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A Time For Review

DEVELOPMENTS in nuclear energy have now passed through the period when rapid progress on a broad front can be expected, when periodic major break-throughs are in the normal course of events, when new and dramatic discoveries are made at regular intervals and have entered upon a period of consolidation and in some cases retrenchment. This is true not only in the United Kingdom where, through the successful launching of the nuclear power programme, a great deal of the industrial effort is concentrated upon actual power station construction and engineering development is concentrated upon ironing out the detailed problems experienced in the overall designs, but applies to the United States, and, so far as one can see, to the U.S.S.R. No longer are we thinking in terms of stage I, stage II and stage III reactors so much as Mk. I, Mk. II and Mk. III designs of the same type of reactor. In this country, of course, the basic design stems from the Calder gas-cooled, graphite-moderated reactor and in the U.S. the water-moderated and cooled reactors are receiving the greatest attention. These two systems can now be considered established, the first for base load electricity generation and the second for naval ship propulsion. It is possible that the Calder type can be engineered to generate electricity economically in small units and the system may be applicable to the propulsion of large ships. Similarly, developments of the water reactor may make it an economic proposition for base load generation in some countries and for small power units in specialized instances. With perhaps the exception of the heavy water-moderated reactor and the organic-moderated and cooled reactor, it is now realized that the immediate prospect for all other systems is anything but rosy.

It is, therefore, opportune that the committees set up by the Prime Minister under the chairmanship of Sir Alexander Fleck have recently been studying the organization and safety problems in the United Kingdom Atomic Energy Authority. Their findings have now been published in the form of White Papers — Commands 338 and 342. Both reports emphasized the big shortage of trained staff available in the Authority, or for that matter in the country.

Total expenditure is another important consideration and although nuclear energy offers one of the most rewarding fields for national investment our resources are limited. All this adds up to the simple conclusion that we must cut our coat to match our cloth, with the corollary that it is essential that the coat we do cut is the coat we need.

In strengthening the sections responsible for operation some effort must be diverted from other projects and a careful examination is therefore required of the whole field of development to determine which of the projects can be abandoned and which are essential to maintaining our lead in the peaceful applications of atomic energy. Without a Fleck report this review would have been necessary, and now is the most convenient time. The initial rush of work concerned with the first round of tenders is over, the Dounreay site is not quite complete but has reached an advanced stage of construction, the first feasibility study on the large tanker has been completed, no second round of tenders will require immediate examination and, in addition, certain personnel movements have required some re-organization. Once appropriate staff has been ascribed to the running of existing plant there are certain additional projects which require an all-out effort. These concern the further engineering development of the gas-cooled reactor, research into the physics and metallurgy of plutonium as a fuel, the development of stable non-metallic fuel elements, the preliminary evaluation of the organic-moderated reactor and the heavy water-moderated reactor and a continuation of the research into the thermo-nuclear reactor. All these projects involve a considerable amount of side effort in the provision of specific plant, components, instrumentation and the like. Long-term research cannot, of course, be abandoned; the long-term research of today provides the essential grounding for the valuable technological developments of a few years hence, but with the limited effort available, the Atomic Energy Authority cannot afford to digress into outlying fields and must either hand over the research in these fields to the universities or other organizations appropriately equipped or must abandon the projects. It has always been our policy to avoid diversification of effort and as in the early days, we must concentrate our efforts on a few lines of attack only; if we can be as right in our choice of these lines today as we were from 1946 to 1950, we can still maintain our leading position in the world.

The Fleck Reports

THE report of the committee appointed by the Prime Minister "to examine the organization of certain parts of the United Kingdom Atomic Energy Authority" deserves the consideration of organizations outside the A.E.A. as many of the points discussed are generally applicable to all manufacturing and development complexes. The criticisms and the recommendations would be valid to a great extent in most large establishments and those concerning the availability of highly qualified people are a source of national concern. The report emphasizes the considerable quantity and variety of effort of the Authority and the very great burden that has been imposed upon the few executive senior staff. It is emphatic in its recommendations that more staff should be appointed to share the load and that, where necessary, cuts are made in the programme to prevent over-burdening of the top management.

In addition to appointing new staff to support the Managing Director and the Works General Managers, it is emphasized how necessary it is that the proper chain of command should be clearly defined and that all senior members have a clear understanding of their functions and responsibilities. From the point of view of the Authority as a whole, the report does not suggest interfering with the present arrangement of three groups, but considers it pertinent to suggest that at some early date an internal examination might be undertaken to see whether the existing degree of decentralization is the most appropriate in the present circumstances of the Authority. (The summaries of the conclusions listed in both reports are detailed on page 46.)

One particular aspect of the Authority's organization that does come in for criticism is the liaison between the groups and the general co-operation between sections. In any rapidly expanding field, or even in any large organization, jealousies are bound to arise and some friction inevitably develop either between groups working on similar projects or, perhaps, between individuals. In the A.E.A. political factions had developed to an uncomfortable extent, which resulted not only in work being duplicated but at times in decisions being taken without the dispassionate approach that one might expect. In the past 12 months there appears to have been an easing of the tension and there are signs that the traditional rivalries between the industrial and research groups are becoming less vigorous. It is to be hoped that this trend will continue as, although the Fleck Committee have recommended certain mechanical steps that can be taken to improve liaison, by the establishment of committees which include members from other groups, full co-operation can only be obtained between individuals.

Health and Safety

As was to be expected, the investigation into the "organization for the control of health and safety in the United Kingdom Atomic Energy Authority" showed that the general organization was sound and that the chief deficiency was again the total number of staff. In the whole of the Atomic Energy Authority this number is 90 qualified technical staff, working full time in the safety field. In addition to increasing its own safety staff, a strong recommendation is made that the Authority should provide for the training of safety personnel whose activities will extend beyond the A.E.A. establishments. There are many industrial organizations now dealing with radioactivity and, although most of these have appointed official departments or individuals to take charge of the safety aspects, in most cases there has been no formal training, except that obtained during the reactor school and isotope school courses and, although the basic regulations concerning radiation maximum permissible levels are reasonably specific, instruction is required on codes of practice and organizing for safety. Mention has been made previously of the necessity for defining levels of exposure for short-term incidents.

One of the problems facing the Authority is the very large number of Ministries and official organizations which are concerned with any major project. Clearly a high degree of co-ordination is essential between these various bodies and the report recommends that the Atomic Energy Office should be built up to enable it to play the leading rôle and to ensure that all necessary action is initiated in good time.

This would seem to be a logical step as the Atomic Energy Office will have direct access to all the relevant nuclear information and will be able to call upon expert advice on all aspects of nuclear technology and radiation biology. One difficulty that must be surmounted is the reaction of the general public to this arrangement, which may feel that a more independent organization, such as the Ministry of Labour and National Service, would be in a better position to co-ordinate the others and present a front independent of the A.E.A. As this Ministry would, however, need to obtain the bulk of its information from the A.E.A., the additional machinery that this would need would only complicate the issue further without changing the situation in essence.

On the question of public reaction, the industrial accident at Aldermaston showed how concerned the general public can become over mishaps at such establishments and emphasizes the necessity for efficient liaison with the local authorities and the Press. In times of such emergency, naturally the primary concern is to prevent the accident spreading, to see that the injured are properly treated and that their immediate relations are warned. Outside interests can easily be forgotten, but in the time intervening between the beginning of rumours and a final public statement a great deal of disquiet can have been caused and the relations between the Authority and the general public have, as a result, been damaged. It is vital that establishments carry a staff whose direct responsibility is to keep the local population informed and whose first concern when troubles arise, even if they are only domestic, is to see that the wrong impression is not created, but that the story is accurate from the beginning.

Commentary

Fusion Information Release

Both Sir Edwin Plowden for the U.K.A.E.A. and Mr. Strauss for the U.S.A.E.C. have found it necessary recently to quash rumours that research into the control of the thermo-nuclear reaction was being kept secret because of the reluctance on the part of the U.S.A. to acknowledge British achievements in this field. The source of these rumours is a little difficult to trace and although there is some evidence that some sections of the A.E.A. may have been concerned initially, there seems little doubt that the recent pronouncements are simple statements of fact and are not part of some deep-laid political plot. The United Kingdom and America are working in the fullest co-operation in this field and to avoid duplication of research effort inevitably each country progressively moves ahead of the other, as new work is got under way. It just so happens that the generation of neutrons, probably by the thermo-nuclear reaction, has been achieved for the first time in this country. This is, of course, a gratifying fact but must be regarded in a proper perspective and too much emphasis should not be laid on this event. Joint effort by the two countries is to be welcomed, but if each individual step forward is to be made a subject of national propaganda, then relations between the two groups must suffer. At the same time the Authorities should note the unrest that is being caused and realize that over-security inevitably generates trouble.

At the end of January a full statement will have been made by the two countries outlining the experimental programme and detailing some of the apparatus used; we shall be reporting and commenting on this in our next issue.

O.E.E.C. Activities

The council of the O.E.E.C. adopted at the end of the year the statute of the European Nuclear Energy Agency and signed a convention on security control. At the same time, twelve member countries of the organization signed the international agreement setting up a first joint undertaking, the European Company for the Chemical Processing of Irradiated Fuel (Eurochemic). The Agency comes into force as from February 1, 1958. Provision is made for security control guaranteeing that materials and equipment, etc., cannot be used for military purposes. This will follow closely the rules defined in the statutes of the International Atomic Energy Agency and Euratom.

The processing plant to be set up by Eurochemic will be erected at the nuclear research centre at Mol in Belgium and will have a capacity for treating approximately 100 tons of natural or slightly enriched uranium per year. The throughput of this plant is, of course, small, corresponding to the demands of just one of the power stations now under construction in the U.K. It is envisaged, however, as a pilot plant catering for fuel elements from research and test reactors and building up experience to enable a much larger plant to be erected to treat spent fuel from the power stations that will be built across Europe. Some doubt, however, must be expressed on the value of this project as considerable experience is now available on the operation of Windscale and if the pilot plant is to take fuel elements from research and test reactors then one would have expected that provision would be made for the treatment of highly enriched fuel. We suggest that in its anxiety to get started O.E.E.C. might find itself operating a plant which has little industrial application and which does little to extend our knowledge.

Windscale Investigation

It is good to see that a team from the United States has visited this country to co-operate with the Industrial Group in the investigation of the recent overheating of the Windscale reactor. It is understood also that France has not been left out of the picture and some co-operative discussions have taken place. Although the Windscale pile is a military reactor, the implications of the November accident are too great to be clothed under the military veil. It is essential that the information that can be gleaned from the results of the fire is widely distributed so that operators of similar plant can learn from our unfortunate experience. In all these technological developments there is the temptation to regard the results as commercially secret and of too great a value to distribute, but where the health and safety of the population is concerned the first consideration must be to ensure that the incident is not repeated elsewhere. If we give a lead in this matter it is possible that the results of other accidents will be made public and a series of case histories can be built up. This could be of enormous value to reactor designers and operators the world over.

New Exposure Limits in the U.S.

The U.S.A.E.C. has approved for use in its facilities and those of its contractors new maximum permissible radiation exposures recommended by the National Committee on Radiation Protection and Measurement. The new levels will make only marginal differences to normal operation and concern chiefly life exposure and population exposure. In areas where radiation levels are monitored and controlled, a new provision limits the total radiation dose any individual may accumulate beyond the age of eighteen, to an average of 5 rem per year and not more than 15 rem in any one year. One important modification concerns the maximum permissible concentrations in air and water of radioactive substances that tend to be distributed evenly throughout the body or to be concentrated near the gonads. For operators in monitored areas this has been reduced to one third of the values previously specified. The maximum permissible concentrations of other substances such as strontium-90 remain at previous levels. Recommendations concerning the population imply that industrial operators must not release any radiation which might be expected to expose members of the populus to an average whole body dosage exceeding 0.5 rem per year or an average concentration of radioactive material exceeding one tenth of the maximum permissible concentrations for occupational exposures. This requirement effectively limits exposures to the public to one tenth of the dosage allowed for workers in atomic energy establishments.

Recommendations of the Fleck Committees, Cmds. 338 and 342

Headquarters

(i) The essential unity of the Industrial Group should be preserved; no major change should be made in its organization.

(ii) Two deputy Managing Directors should be appointed to assist the Managing Director; all three should be substantially free from routine duties.

(iii) The Board of Management should include a Director, appointed for a limited period, with the specific responsibility of ensuring liaison with other Groups and appropriate external bodies.

(iv) The Board of Management should include a few visiting members from other Groups.

(v) The Board of Management, consisting of the Managing Director, his Deputies, the Directors in charge of Branches and the other members, should assume collective responsibility for all the activities of the Industrial Group.

(vi) The Headquarters of the Operations Branch should be provided with additional technical staff and should be reorganized in accordance with the proposals set out in paragraphs 83-87.

(vii) The Administration Branch should be renamed Personnel and Administration Branch and strengthened, and its status consequently enhanced.

(viii) The problems of Dounreay should be carefully considered within the Authority and a new Director should be appointed to take charge of this site. He should have a seat on the Board of Management of the Industrial Group.

(ix) The committee structure relating to Industrial Group operations should be reviewed.

Works

(i) The existing practice of appointing Works General Managers to the major establishments of the Industrial Group should continue. They should be supported by a number of Works Managers responsible for individual plants.

(ii) A separate Works General Manager should be appointed for Chapelcross, with responsibility direct to Operations Branch Headquarters.

(iii) The chain of command at the Works under the Works General Manager should be clearly laid down; to maintain this, arrangements should be made to ensure that, in the event of absence of senior staff, their deputies or persons nominated in advance would act for them.

(iv) The Works General Manager should be a good technologist and the number of scientists and technologists available to him should be substantially increased.

(v) The interchange of staff between the Operations Branch and the Engineering and Research and Development Branches and the other Groups of the Authority should be encouraged.

Health and Safety

(i) We endorse the Authority's decision to establish a committee of the Atomic Energy Executive to be responsible for the overall supervision of all matters of health and safety. We recommend some minor changes to the terms of reference. The form we favour is given in Appendix I.

(ii) We consider that the new committee structure established under the Executive Committee on Health and Safety provides an effective means of controlling health and safety throughout the Authority. We endorse the terms of reference of the Weapons Safety Executive Committee, but recommend some modifications to those of the Executive Committees dealing with Health and Safety respectively. The terms of reference which we recommend for all three Committees are given in Appendix II.

(iii) We recommend that the management of health and safety in the factories of the Industrial Group should be fully integrated into a single section responsible directly to the Works General Manager. A chart showing the typical organization we recommend is given in Appendix III.

(iv) We endorse the new health and safety organization at Risley and the concept of an Authority Safety Branch which it contains. We recommend that this organization should be brought up to strength as a matter of urgency.

(v) We consider that the terms of reference of the Industrial Group Health and Safety Branch should be as specified in Appendix IV.

(vi) We recommend that there should be one senior member of the scientific staff at the Radiochemical Centre whose principal duty would be functional responsibility to the manager for all safety matters. Existing members of the staff should be given this duty on a rota basis. One of the first tasks of the new safety officer should be to investigate storage arrangements for radioactive materials.

(vii) We recommend that the Authority should review their present procedures for the publication of information about accidents with a view to giving a prompt account of such occurrences in as much detail as may be appropriate.

(viii) We recommend that the Authority should bring the site emergency procedures in each of their establishments to a uniformly high standard. They should be co-ordinated to ensure that the maximum technical resources of the whole Authority may be deployed to counter an emergency in any single establishment.

(ix) We recommend that there should be closer collaboration between the Authority's three Groups on the problems concerned with the control of criticality. Each Group should have a nominated officer to bear functional responsibility for criticality problems.

(x) We recommend that the Atomic Energy Authority should take the lead in building up the supply of the specialist medical staff required for the control of health and safety as the uses of atomic energy become more widespread.

(xi) We recommend that the Atomic Energy Authority should establish a national training centre for health physics and nuclear safety staff (under the administration and general supervision of the Research Group). Courses should be graduated to suit all levels. They should cover not only problems of protection against radiation hazards, but also the health and safety aspects of the use of isotopes in medicine, agriculture and industry.

(xii) We recommend that Government Departments should be directed to ensure that appropriate training in radiological problems is given in the public services and industries for which they are responsible.

ENERGY STORAGE

Possible Methods and their Relative Economics

By K. M. TOWERS

In order to provide a high load factor for nuclear power stations some form of energy storage may be necessary. This article discusses the various methods available and their economic possibilities.

THE importance of operating nuclear reactors continuously is by now well established. There may be technical reasons for this in addition to the powerful economic incentive of utilizing high capital cost plant to the full.[1] At present only countries which have a fully developed electrical distribution system can achieve near-continuous operation of nuclear reactors and even these, within the next 20 years or so, will probably have exceeded their nuclear base-load requirements. The cost of electricity generated by nuclear power stations is much more sensitive to load factor than the cost of electricity from coal-fired stations on account of the high proportion of capital charges. Therefore, some form of load factor improvement may become necessary when the nuclear base-load requirement is exceeded in order to prevent the cost of nuclear generated electricity from steadily increasing as the nuclear station system load factor decreases.

In this article the economics of some energy storage schemes are examined in order to try and determine which, if any, are of immediate importance and which are most likely to repay further research and development.

Possible Methods of Energy Storage

There are two fundamental methods available for the storage of energy:—(a) chemical energy; (b) potential energy.

The possible choice afforded by (a) and (b) above is extensive. However, in practice it is limited by the need to use cheap, abundant raw materials or simple closed-cycle operations for (a), and a cheap working fluid for (b). For these reasons the schemes considered here are confined to six, viz., electrolysis of water (at atmospheric and high pressure), production of sodium and aluminium, production of liquid methane from CO_2 and H_2, pumped water storage and compressed air storage.

Electrolysis of water.—Using electric power, water is electrolyzed giving hydrogen and oxygen. These gases can be stored at any pressure dependent upon subsequent requirements and reconverted to electricity by combustion or by a hydrogen/oxygen fuel cell. Both the conventional atmospheric pressure and the as yet commercially untried high pressure (30 at) routes are considered.

Production of aluminium.—Electric power is consumed in the production of aluminium metal. It has been suggested that aluminium could be utilized as a fuel, to recover the stored energy by both combustion and in an aluminium/oxygen fuel cell.[4] It must be stressed that the utilization of aluminium is speculative and considerable development would be required should this method be shown to be economically attractive.

Production of sodium.—Sodium and hydrogen are produced by the electrolysis of caustic soda. The energy available as hydrogen can be recovered as detailed previously and the sodium can be reacted with water to raise steam and further hydrogen. It has also been suggested that sodium could be used in a fuel cell[5] but again this must be regarded as a speculative alternative.

Production of methane.—Energy in the form of methane can be produced by the reaction $CO_2 + 4H_2 \rightleftarrows CH_4 + 2H_2O$. Electric power is consumed in producing the hydrogen by electrolysis of water and in the recovery of carbon dioxide from, say, flue or calcining waste gases. Liquid methane can be conveniently stored, and can be reconverted to electricity in conventional generating plant or used direct as a fuel, e.g. internal combustion engines, domestic heating.

Pumped-water storage.—Water is raised to an elevated storage installation by steam-turbine driven pumps. The potential energy so produced is recovered as electricity by water turbo-alternators.

Compressed-air storage.—Air is compressed by motor-driven compressors and delivered to steel pressure vessels for storage. The stored energy is recovered as electricity by air-driven alternators.

It will be observed that all six processes utilize nuclear heat in the form of electricity and they are, therefore, unlikely to have efficiencies greater than 35% for the initial conversion of heat to work.

The reactor generates energy primarily in the form of heat and, theoretically it is possible to utilize this directly to supply endothermic heats of reaction to generate or upgrade chemical energy. For instance, water can be converted to chemical energy in the form of hydrogen, and coke upgraded in heat content by reaction with steam to produce hydrogen—both reactions requiring the addition of heat. In general these reactions require very high temperatures but at the same time offer the advantage of high conversion efficiencies. Unfortunately, there are no processes yet available for large-scale application which can take advantage of this more efficient process.

Factors Affecting Possible Routes

The various factors which determine the cost of any storage system can be summarized under the following headings:

(a) Volume per unit of energy stored.
(b) Efficiency of conversion from primary energy source to stored energy.
(c) Efficiency of reconversion of stored energy to useful work.
(d) Capital and operating charges of conversion.
(e) Capital and operating charges of reconversion.
(f) Capital cost of storage.

Calculated values for these are detailed in Table 1. In all six schemes the figures for efficiencies and costs are based

on large-scale production for the chemical processes and large machines for pumping and compression. The values in Table 1 indicate that chemical energy requires far less space than potential energy per unit of stored energy, and consequently chemical energy will be considerably cheaper to store.

However, the overall efficiencies for the conversion of electrical energy to stored energy and the recovery of electrical energy from stored energy are low for the chemical energy methods, the highest practical figure being about 20% compared with about 70% for potential energy methods. Considering the whole cycle of nuclear heat conversion to electricity via energy storage the overall efficiency of the best potential energy method is about 20%, whereas the overall efficiency of the best chemical energy method is about 6%. The overall efficiency of the best chemical energy method would be raised to 12% if a hydrogen/oxygen fuel cell could be used to regenerate electricity but even so the potential energy cycle remains twice as efficient as the chemical energy cycle.

Also Table 1 shows that the capital costs involved in the conversion and reconversion steps favour the more simple operations performed in the potential energy methods.

Cost of Off-peak Electricity

For large nuclear power stations of the type being built in Britain, the cost of off-load power might reasonably be taken as the sum of operating and fuel costs—about 0.35d/kWh s.o.[2]—less the credit for production of fissile material in the pile plus some small contribution to the capital charges. Assuming the last two factors cancel themselves out the off-load power cost would be about 0.3-0.35d/kWh s.o.

The cost of off-load power from small (5-20 MW) nuclear power stations serving a small local community will probably be greater than for large stations. Electricity costs increase rapidly with decreasing capacity below about 50 MW(E) mainly due to increasing unit capital cost, but enrichment may also increase the fuel charges. It is only possible to hazard a guess that off-load power will cost about 0.4-0.5d/kWh s.o. from such small nuclear power stations.

Cost of Energy Production for Storage

The production costs for the six processes under consideration have been estimated and these are shown plotted against the cost of off-peak-load power in Fig. 1 (where the process uses energy in the form of steam then the steam cost corresponding to the equivalent electricity cost has been taken, e.g. electricity at 1d/kWh is equivalent to steam at 19s 6d per ton).

The fixed charges on capital have been assumed to be 10% per annum for the chemical plant and 7½% per annum on the large mechanical equipment (pumps, compressors, etc.) for pumped-water and compressed-air storage. Interest rates are assumed to be 4½% which gives a lifetime of about 14 years for the chemical plant and 20 years for the mechanical equipment. Other operating costs for the six processes were mostly available, but in some cases it was necessary to assume a maintenance charge of 5% per annum of the capital cost and an overhead charge of 2% per annum of the capital cost.

TABLE I

Process	Storage volume required ft³/kWh (thermal)	Efficiency of conversion. Electricity to stored energy %	Efficiency of reconversion. Stored energy to electricity %	Overall efficiency %	Capital cost of conversion £/kW thermal capacity	Capital cost of reconversion £/kW generating capacity	Capital cost of storage £/unit volume required for 1 kWh
Pumped water	50-ft head~850 100-ft head~425 500-ft head~85	80–85	80–85	65–72	11 pump	10 water turbine	100 55 12.5
Compressed air	20 at~66.7 100 at~12.8 200 at~6.67	75–80	80	60–65	25	10	90–120 up to 150 at. Special constructions at higher pressures
Water electrolysis			Fuel cell 50–70	1. 30–42 via fuel cell		Fuel cell ?	
1. High pressure 30 at	0.4	60	Combustion 30	Combustion 18	85	Combustion 50–55	0.8–1
2. Atmospheric pressure	12.5	57.5		2. 29–40 via fuel cell Combustion 17	82		
Aluminium	1.53×10^{-3}	30–40	Fuel cell? Combustion 30	Fuel cell ? Combustion 9–12	80–100	—	Negligible
Sodium	7.15×10^{-3}	45–50	Fuel cell ? Combustion 30	Fuel cell ? Combustion 14–15	135–150	—	Negligible
Liquid methane From CO_2 and H_2	6.0×10^{-3}	40–45	30	12–14	200	—	—
Fossil fuel	Coal 4.75×10^{-3} Oil 3.45×10^{-3}	—	30	30	—	55–60	—

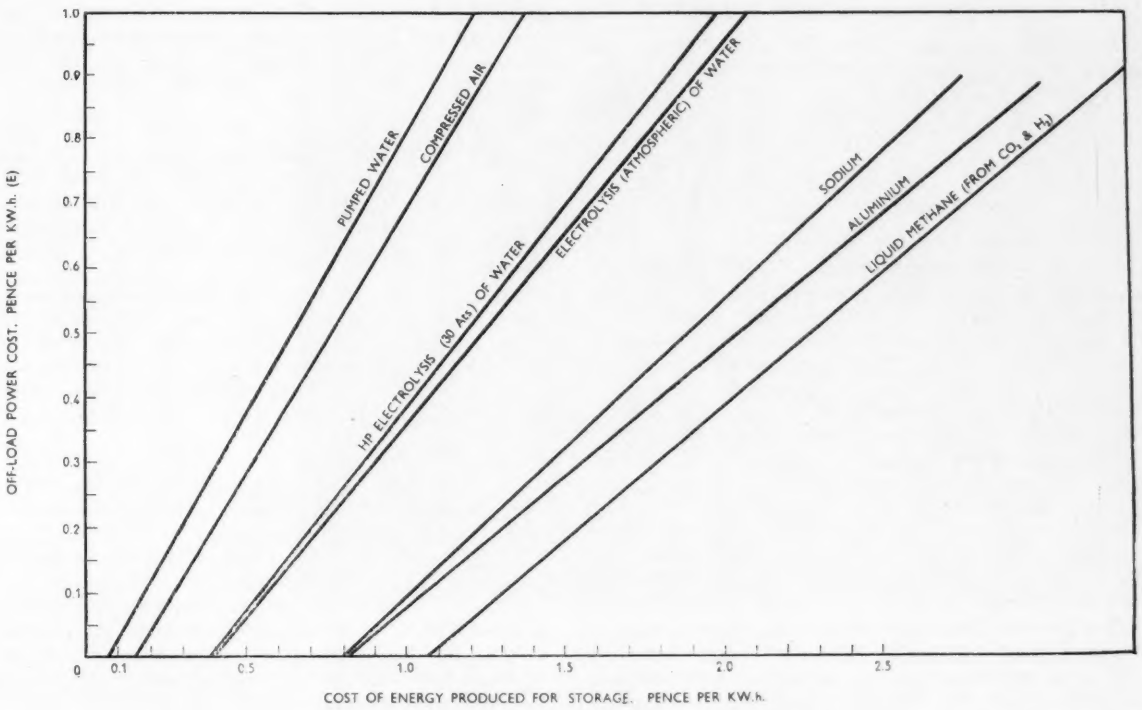

Fig. 1.—Relative costs of various methods of energy storage.

In the cases of sodium and aluminium production closed-cycle operations have been assumed, i.e. no cost is included for raw materials or their processing. For the liquid methane production the carbon dioxide is assumed freely available in flue or calcining waste gases and only the cost of recovery has been included, the hydrogen is that from high-pressure electrolysis.

The curve for pumped water costs was estimated on the use of steam turbines to drive the pumps, i.e. very little extra turbine or alternator capacity will be required over that necessary to meet peak load by conventional means, but some turbine capacity is taken over to drive the pumps and some alternator capacity driven by the water turbines. The curve for compressed-air storage is based on large motor-driven compressors, the capital cost of such a scheme would be slightly reduced and the efficiency slightly increased by the use of steam-turbine-driven compressors. The following points concerning the cost of energy production for storage emerge from an analysis of Fig. 1.

(a) The intercept on the x-axis shows the minimum costs of each process, i.e. when the off-peak load power is available free, and represents the contribution of capital and operating costs to the total costs for any particular process. This value varies from 0.06d/kWh of energy produced for pumped-water storage to 1.06d/kWh of energy produced in the form of methane. The cheapest method of chemical energy production gives a minimum cost approximately six times greater than the cheapest method of potential energy production which clearly demonstrates the economic disadvantages of higher unit capital cost and shorter working lifetime of the chemical energy methods.

(b) The efficiency of conversion of off-peak load power to stored energy is indicated by the slope of the lines. As the angle increases from 0°-45°, so the conversion efficiency increases from 0-100%. Again the disadvantages of the lower conversion efficiencies of the chemical methods are clearly shown.

Finally, it must be borne in mind that the capital and operating charges used in compiling Fig. 1 are only generally applicable in Great Britain. In other countries different conditions such as interest rates, labour and materials costs may exist which would significantly alter the estimates.

Storage Costs

In any scheme which envisages storing energy for reconversion to electricity to meet variations in load demand the amount of storage space required is peculiar to that scheme. For instance, if a power station has an installed capacity of A kW, the daily load factor is L%, S ft³ of storage space are required per kWh of electricity generated from stored energy and Y% of the daily electrical output is required for storage to meet load variations.

Then, daily electrical output $= AL \cdot 24/100$ kWh.

Daily electrical storage requirement $= ALY \cdot 24/10{,}000$ kWh.

Storage capacity required $= ALYS \cdot 24/10{,}000$ ft³.

Storage capacity required/kW of installed capacity $= LYS \cdot 2.4 \cdot 10^{-3}$.

The storage capacity required depends on the load factor and the percentage of the daily electrical output required for storage which in turn are determined by the area under, and the shape of, the daily load curve respectively.

The figures shown in Table 1 are the capital cost of the storage space required for one kWh of energy. These can then be converted to a capital cost per installed kW for any particular case under consideration.

UTILIZATION OF STORED ENERGY

In general most large schemes will be concerned with the reconversion of the stored energy to electrical power, but it may also be required in some different, more mobile form to satisfy a local demand, or in a particular form with unique properties, e.g. very high temperature or reducing atmosphere. The cost of reconversion must, therefore, be estimated for the particular process in view.

(a) Reconversion to Electrical Power

Considering electrolytic hydrogen as the cheapest and most feasible of the chemical energy storage routes (the technical feasibility of converting large quantities of aluminium or sodium to electricity either by means of combustion or of a fuel cell is by no means certain), the lowest cost is about 0.85d per thermal kWh without any charge for storage. (The current cost of hydrogen from oil or coke is about 1.2d/kWh for medium-scale production.[3])

The capital cost, operating cost and overall thermal efficiency for a hydrogen-fired generating plant of conventional design will be very little different from that of a coal- or oil-fired plant. It is permissible then, to compare hydrogen costs with coal or oil costs on a heating value basis. Hydrogen at 0.85d per thermal kWh is equivalent to coal at £28 per ton or oil at 3s 4d per Imperial gallon.

The possible alternative hydrogen reconversion route is via the fuel cell. As yet no one claims the hydrogen-fuel cell as a working proposition although recent publications[4,5,6] indicate the size and efficiency of such a cell operating under a pressure of 30 at and at 200°C, with 27% aqueous KOH as electrolyte and sponge nickel electrodes. It seems that a reasonable working efficiency is around 55-60%, which gives an apparent electrode area of 2.15 ft²/kW (efficiency 60%). The author has not seen any estimates that may have been made of the capital or operating costs (excluding the fuel gases) of such a fuel cell, but if they are assumed to be the same as for conventional generation plant then hydrogen at 0.85d per thermal kWh is equivalent to coal at £16 10s per ton or oil at 2s per Imperial gallon when converted to electricity by a fuel cell. Fig. 1 and Table 1 indicate that sources of fuel (hydrogen and oxygen) cheaper than can be obtained by electrolysis will be necessary to make the fuel cell economically attractive for large-scale reconversion to electricity.

The corresponding costs for reconverting potential energy to electricity are much more promising. Here the major item of capital cost is the storage installation itself, and an economic advantage of these systems is the long depreciation time allowable for the storage installations (80 years has been quoted for civil works in pumped storage[7]).

Taking off-peak load at 0.3d/kWh(E) then additional power can be generated for approximately 0.8d/kWh(E) by pumped-water storage and approximately 1.1d/kWh(E) by compressed-air storage. This is equivalent to burning coal at £6-£8 10s per ton or oil at 9d-1s 2d per Imperial gallon in a power station operating at 60% load factor.

(b) Other Uses

Local conditions may suggest special applications. There might be economic justification in some instances because of high freight or distribution costs.

Methane could be used as fuel in internal combustion engines for vehicles or small generating sets on farms, etc. From Fig. 1 the lowest cost of producing liquid methane is about 1.665d per thermal kWh or 3s 8d per Imperial gallon. For use in an internal combustion engine one gallon of methane is approximately equal to 0.7-0.8 gallons of petrol, depending on the mode of operation.[3] Liquid methane can only compete then with imported petrol at 4s 7d-5s 3d per Imperial gallon.

Hydrogen could be put to many uses, e.g. ammonia production for fertilizers, hydrogenation to produce local synthetic oils, fuels or edible fats. The economics of any such scheme will depend on local conditions and can only be considered in relation to these.

There might also be a case for selling the stored energy in the form of metals such as sodium, aluminium, calcium, etc., i.e. utilizing off-peak-load electricity for electrowinning of metals. However, the economics of such a

Les Possibilités Economiques de l'Emmagasinage de l'Energie Associé à l'Energie Nucléaire

Les méthodes d'emmagasinage de l'énergie produite par les réacteurs nucléaires sont étudiées. On en conclut que seul l'emmagasinage d'eau pompée a des chances d'en valoir la peine du point de vue économique et cela a l'inconvénient de nécessiter un terrain qui convienne spécialement. Les cellules de combustibles pourraient présenter un attrait pour les applications spéciales si elles peuvent être développées de façon à opérer avec sûreté dans des conditions industrielles, mais des sources d'hydrogène et d'oxygène, à meilleur marché que celles qui peuvent être obtenues par électrolyse à l'heure actuelle seront requises.

Les méthodes chimiques d'emmagasinage d'énergie offrent les plus grandes possibilités de développement ultérieur, l'exploration des méthodes de production d'hydrogène étant considérée comme le moyen le plus digne d'une étude supplémentaire. Ce gaz peut être emmagasiné et est de grande valeur comme produit chimique ou comme source de combustibles gazeux et liquides.

Die Wirtschaftlichen Möglichkeiten der Speicherung von Energie im Anschluss an die Nutzung der Atomkraft

Es werden die Möglichkeiten der Speicherung von in Kernreaktoren gewonnener Energie untersucht. Der Autor kommt zum Schluss, dass nur die Speicherung in gepumptem Wasser Aussicht auf wirtschaftlichen Erfolg hat, der Nachteil ist aber, dass ein geeignetes Gelände erforderlich ist. Brennstoffzellen können für Spezialaufgaben interessant sein, wenn sie sich für zuverlässigen Betrieb unter Industriebedingungen entwickeln lassen, es würden aber Wasserstoff- und Sauerstoffquellen benötigt, die diese Stoffe billiger liefern, als zur Zeit mittels Elektrolyse möglich ist.

Chemische Verfahren der Energiespeicherung bieten die grössten Aussichten auf Erfolg, wobei Auffindung von Verfahren für die Wasserstofferzeugung als lohnendste Forschungsaufgabe betrachtet wird. Wasserstoff lässt sich gut speichern und ist als chemischer Grundstoff bzw. Quelle gasförmiger und flüssiger Brennstoffe sehr wertvoll.

Las Posibilidades Economicas del Almacenaje de Energia Asociadas con la Energia Nuclear

Los métodos de almacenar la energía producida por los reactores nucleares son estudiados. La conclusión a que se llega es que el almacenaje de agua achicada por bomba es el único método que posiblemente valga la pena del punto de vista económica, pero este método tiene la desventaja de exigir terreno especialmente adecuado. Es posible que las células de combustible se vuelvan atractivas para aplicaciones especiales, si es que pueden ser evolucionadas para operar con seguridad en condiciones industriales, pero para ésto tendrán que haber fuentes de hidrógeno y oxígeno más baratas que las que se obtienen de la electrólisis en la actualidad.

Para futuras evoluciones, los métodos químicos de almacenaje de energía ofrecen la más amplia esfera de acción, consideránse que la exploración de métodos de producción de hidrógeno vale la pena de estudiarse con más detenimiento. Este gas puede ser almacenado y es valioso como un producto químico o como una fuente de combustibles gaseosos y líquidos.

A general view of the site for Great Britain's first pumped storage scheme, at Blaenau Ffestiniog.

practice are again tied to local conditions, for, apart from having to have either local raw materials or easy access for imported raw materials, the power available to the metal production process would be the balance remaining after satisfying other demands. Therefore, a load factor would have to be applied to the capital and operating charges of the metal production process and this may more than offset the credit of cheaper power.

Conclusion

Although it is important to operate a nuclear reactor continuously, utilization of the off-peak load to produce chemical energy for storage does not at present appear to be a feasible economic proposition for either a fully integrated generating network or small, local networks. Methods of potential energy storage are more economically attractive if regeneration to electricity is required.

If future research should produce a hydrogen/oxygen fuel cell that is cheap, robust and compact with an efficiency of 60% or over and high-pressure electrolysis of water is developed to give higher efficiencies, then chemical energy storage in the form of hydrogen and oxygen might begin to compete with potential energy methods under certain conditions (e.g. water storage at low head). The fuel cells may also be economically attractive for the medium range of traction vehicles, i.e. buses, heavy lorries and short-distance trains in that the fuel is likely to be cheaper than processed oil and the capital outlay necessary for electrification of railways considerably reduced.

There may be some justification for utilization of off-peak load nuclear power to produce chemical energy in some of the more isolated regions of the world. The economics of any such scheme will be closely linked to local conditions and can only be considered in relation to these conditions. It must be borne in mind, however, that any such scheme must show more than just a marginal gain over existing conditions on account of the high capital costs which would be entailed.

It appears, then, that in the immediate future there is no general economic justification for energy storage associated with nuclear power generation other than perhaps pumped-water storage. However, even this can only be regarded as a temporary measure as the amount of pumped-water storage capacity in any one country is limited for topographical reasons.[8] This is especially so in Great Britain, a recent survey putting the capacity at 2,000 MW for England and Wales.[1]

Finally, while the immediate future of energy storage associated with nuclear power seems to be with pumped-water storage, the long-term prospects would appear to be with chemical energy storage, as these methods offer the possibility of avoiding the initial heat/work cycle with its thermodynamic limitations, and the energy produced can be easily and cheaply stored as and where it is required.

The chemical which seems most likely to fulfil the conditions necessary for economic storage is hydrogen if it can be produced direct from nuclear heat and water. Not only does this offer a potential economic competitor to pumped-water storage when hydrogen is converted to electricity by combustion, but coupled with a fuel cell it offers an overall conversion efficiency of heat to electricity of 45-50% combined with flexibility in meeting local demand. In addition chemical energy in the form of cheap hydrogen could be utilized in very large quantities by the synthesis and iron-producing industries.

Acknowledgment

The author wishes to express his appreciation to Mr. C. M. Nicholls of A.E.R.E. Harwell and Mr. R. G. Tongue of W. J. Frazer, Ltd., for their helpful comments and discussions, and to the directors of the Power-Gas Corporation, Ltd., for permission to publish the article.

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MAGNESIUM and its ALLOYS

Applications in Nuclear Engineering

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Magnesium has attracted attention as a potential canning material primarily because of the low neutron absorption cross section and excellent compatibility with uranium. Other requirements have been met by the development of the Magnox series of alloys.

THE use of magnesium for purposes other than photographic illumination and as a deoxidant was largely due to the aircraft industry which, in its search for high strength light alloys, showed that magnesium had possibilities for structural components, and this process was accelerated by war conditions, leading to a considerable development in magnesium production.

Although magnesium is superior to aluminium in respect of compatibility with uranium and neutron absorption, aluminium was used as a canning material for Windscale, since time did not permit a demonstration of the stability of magnesium in contact with the coolant gas at elevated temperatures, or the development of satisfactory production methods. At the time of the design of the Calder Hall reactors the possible retardation of the oxidation of magnesium by beryllium and calcium additions had been studied at Harwell and the high temperature stability in air of the Magnox alloys, which included these additions plus aluminium, had been demonstrated. The Harwell work,[1] taken in conjunction with the improvement in compatibility and increased ignition temperature of the metal with carbon dioxide provided the necessary demonstration of stability at elevated temperatures; allowing the use of magnesium on the assumption that satisfactory fabricating and joining techniques could be evolved in the time available. The problem was satisfactorily solved after development work on a number of alloys in the Magnox series[2] and the alloy Magnox A12, from which the calcium had been eliminated to improve weldability, was chosen.

The A12 cans in use at Calder Hall, and as designed for the Chapelcross and C.E.A. reactors, function somewhat unusually for components of a constructional metal, in that they operate as ductile extensible envelopes. The only strength requirement is that of sufficient high-temperature creep strength for the radial fins to retain their profile under the pressure of the coolant gas stream.

Occurrence

Magnesium is the third most abundant metal in the earth's crust and its ores are readily adaptable to modern methods of beneficiation and extraction. Sources are not limited to solid minerals, as all brines, including sea-water, contain a sufficient percentage of magnesium salts to justify recovery and chemical reduction on a commercial basis. The principal ores are dolomite ($MgCO_3 CaCO_3$), magnesite ($MgCO_3$), carnallite ($KMgCl_3 . 6H_2O$) and brucite ($Mg(OH)_2$). In brines, magnesium occurs as a chloride.

Extraction

Wartime demands for the production of magnesium have led to the development of three successful processes based on electrolysis of the chloride, or thermal reduction, by carbon or silicon, of the oxide. The Dow Chemical Co. obtains magnesium chloride for electrolysis by mixing sea-water with lime and filtering off the insoluble magnesium hydroxide. This precipitate is then treated with hydrochloric acid, and the product evaporated and dried. Subsequent electrolysis of molten anhydrous magnesium chloride produces magnesium metal and chlorine gas. The latter is used in combination with natural gas to produce the hydrochloric acid used in the process, while the lime required for the initial treatment of the sea-water is normally obtained by roasting sea shells.

Thermal reduction processes are of lesser commercial significance. The more widely used reduction by silicon is carried out by the Pidgeon process which comprises the reduction of calcined magnesite or dolomite by ferro-silicon, carried out at 1,150°C in cylindrical retorts at very low pressures, the magnesium vapour condensing in the cooler end of the retort as crystalline rings of metal. The carbon reduction is carried out at about 2,000°C, the end product being a fine dust, which has to be briquetted and distilled to produce ingot metal.

PHYSICAL PROPERTIES

The crystal structure of magnesium is close-packed hexagonal, with an axial ratio c/a equal to 1.623. The structure therefore closely approaches the ideal close-packed structure (c/a=1.633) and the properties of the metal, for example the high ductility and the high thermal conductivity, are generally in accordance with this fact. The density ranges from 1.74 g/cm³ at 20°C to 1.64 g/cm³ at the melting point and it is the lightest metal in common use.

The low volume change on solidification (4%), again typical of a close-packed structure, simplifies the problem of casting the metal, while the high vapour pressure allows ready purification by sublimation or distillation in vacuo. At likely future maximum coolant temperatures of the order of 400°C the vapour pressure exceeds 1×10^{-3} mm Hg and any advance on this temperature would raise the possibility of appreciable mass transfer of magnesium to cooler parts of the circuit. In view of the high heat of combustion (145,000 cal/mole) it is essential to ensure that possible reactor transients cannot approach the ignition temperature of magnesium in carbon dioxide at the operating pressure. The heat generated could well be sufficient to lead to spreading of local ignition resulting in severe damage to the pile and the possibility of a major reactor incident.

The metal has a relatively high coefficient of thermal conductivity and of thermal expansion, both being very similar to aluminium. The high coefficient of thermal conductivity is of advantage in the transfer of heat from the fuel to the coolant, but the high coefficient of thermal expansion (28×10^{-6}) relative to uranium (17×10^{-6}) [3] can lead to the development of stresses due to differential length

changes during pile temperature fluctuations. It is necessary to ensure that these stresses are distributed as uniformly as possible over the body of the can, and are not allowed, for example, to concentrate on the welded joints to the end fittings. Anti-ratchetting grooves are, therefore, machined at intervals in the uranium bar and, after sealing, the cans are pressurized into these grooves at a temperature of the order of 500°C.

The coefficient of expansion is found to be greater parallel to the hexagonal axis than perpendicular to it and this anisotropy extends to the alloys. Since (0001) is the primary slip plane the basal plane tends to lie in the plane of maximum deformation, a tendency which increases with the degree of deformation, with the result that the thermal expansion is lower for rolled or extruded material than for

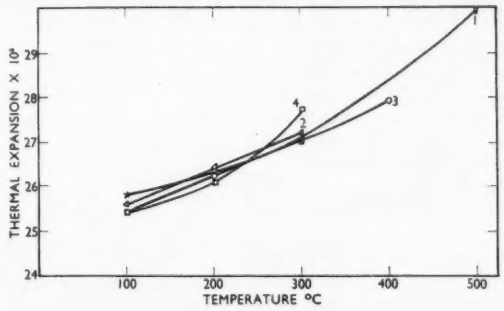
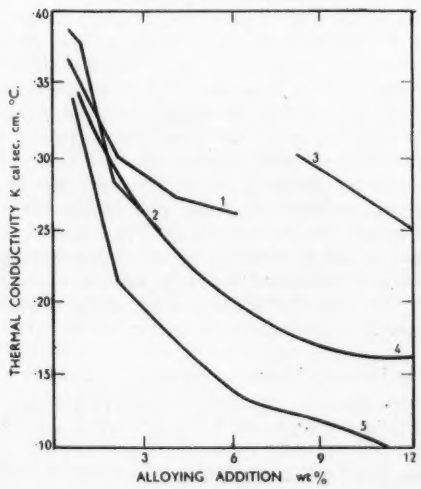


Fig. 1.—Variation in linear thermal expansion of magnesium alloys.
1 Mg/Al 2 Mg/Al/Mn 3 Mg 4 A12

cast material. The mean linear coefficient of thermal expansion for random orientation is 25.8×10^{-6}, whereas material with preferred orientation has a value of 27.1 parallel to the hexagonal axis and 24.3×10^{-6} perpendicular to the hexagonal axis.

In general, there is little difference between the expansion of magnesium and that of its alloys. A slight increase occurs with additions of lead and zinc and a decrease with nickel, silicon, bismuth and tin. Manganese additions have little effect, and Hidnert and Sweeney[4] have shown that alloys containing 4% to 10% Al have expansions almost

Fig. 2.—Effect of alloying on thermal conductivity of magnesium. (After Beck.)
1 Zn 2 Mn 3 Ce 4 Al 5 Al



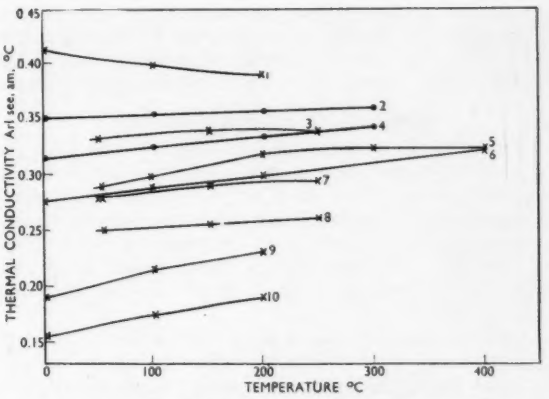


Fig. 3.—Variation in thermal conductivity of magnesium alloys with temperature.
1 Mg 2 AM503S 3 Mn 2.64% 4 ZW1 5 Magnox B 6 A12
7 Mn 1.8% Ce 3.17% 8 Ce 10.19% 9 Al 6% 10 Al 8%

independent of aluminium content. Fig. 1 shows the variation of the mean coefficient of thermal expansion with temperature for magnesium and some of its alloys. In all cases the coefficient increases with rising temperature.

Thermal conductivity is considerably affected by impurity content and heat treatment. All alloying additions reduce the conductivity, the effects of tin, aluminium and manganese being marked and that of zinc and cerium less so (Fig. 2). The thermal conductivity of pure magnesium falls slightly with increasing temperature, but conductivity of all alloys rises with increasing temperature (Fig. 3).

Electrical resistivity increases with temperature and with alloying additions. There is a considerable variation with orientation in materials of preferred orientation. At 18°C the values parallel and perpendicular to the hexagonal axis

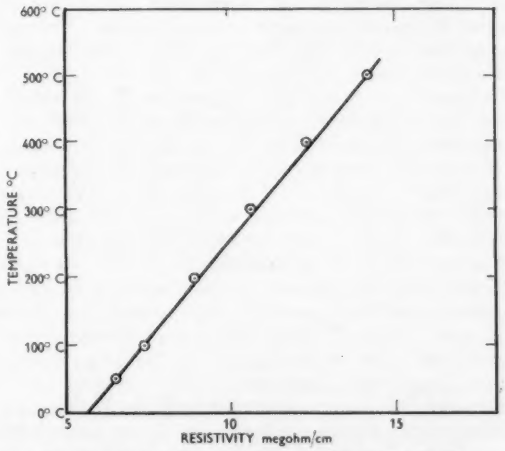


Fig. 4.—Resistivity variation of Magnox B with temperature (27).

are 3.77×10^{-6} and 4.56×10^{-6} ohms/cm compared with a value for material of random orientation of 4.2×10^{-6} ohms/cm. The resistance of rolled material is, therefore, greater than extruded material, which in turn has a greater resistance than cast material. Silver and cadmium increase the resistivity at the rate of 0.015×10^{-6} ohms/cm per 0.1% addition, whereas aluminium, manganese and cerium cause an increase at the rate of about 0.17×10^{-6} ohms/cm per 0.1% addition. Fig. 4 gives the variation of resistivity with temperature for Magnox B, one of the predecessors of the

present A12 alloy, which contains approximately 1% aluminium and small quantities of calcium and beryllium. The resistivity is seen to increase with temperature in the linear manner normal to a metal of close-packed structure.

MECHANICAL PROPERTIES

From the point of view of reactor technology the mechanical properties of magnesium are mainly of interest at temperatures above those for which the metal would be considered for conventional structural purposes so that most published data relate to temperatures below those of interest. Relevant results stem mainly from the U.K.A.E.A. laboratories, or those of the civil consortia engaged on reactor design.

Canning alloys are required to operate in Calder Hall-type reactors as extensible envelopes deforming without fracture under the forces generated by the growth and distortion of the fuel but retaining sufficient creep strength to allow the heat transfer fins to retain their profile under the coolant gas pressure at the highest operating temperatures. The end fittings of the cans, on the other hand, need limited ductility, but must possess adequate high-temperature creep strength to support the stresses due to the weight of the fuel. Experimental work has been concentrated on mechanical properties at temperatures of 200°C and higher. The alloys of current interest are Magnox A12 and minor variations on the beryllium and aluminium content of this alloy, AM503S which is a manganese alloy with a composition range of 0.5 to 1.0 wt.% manganese, ZA which is zirconium alloy with a composition range of 0.5 to 0.7 wt.% zirconium, ZW1 which is an alloy with 0.5 to 0.7 wt.% zirconium and 0.7 to 1.0 wt.% zinc and alloys with approximately 1.0 wt.% of cerium or lanthanum.

With the exception of Magnox A12, and minor variations of the A12 composition, the alloys are potentially heat-treatable alloys whose properties are very dependent on their history. In addition, like alloys of other metals, the mechanical properties of magnesium alloys are very dependent on both the grain size and rate of deformation during test, so that properties specified in the absence of those variables are of limited value.

In general, at tensile rates of strain greater values of elongation to fracture are obtained than for creep rates of strain, while fine-grained material gives greater elongations to fracture than coarse-grained material. These points are brought out in Section B of the Data Sheet. The coarse-grained (0.024 in.) Be-free version of the A12 alloy (Table B6) is seen to give elongations to fracture of 5, 6 and 10% at 200°C for stresses of 1.25, 1.5 and 1.75 ton/in.^{2}, whereas in the fine-grained as-extruded form (0.0012 in.) elongations of 42, 42 and 48% are obtained for the same conditions. Similarly, heat-treated (and therefore coarse-grained) A12 has an elongation to fracture of 6% at 1.5 ton/in.^{2} at 200°C (Table B5).

Although it is not possible to define closely the rates of elongation occurring in-pile due to the growth and distortion of the fuel, it is quite certain that these will be creep and not tensile rates. Hence the lower elongations to fracture at slow rates of strain will be those relevant to service conditions. A factor of considerable importance in this connection is that micro-examination of specimens after rupture, particularly for slow rates of strain, disclosed the formation of cavities of spheroidal or ellipsoidal shape mainly at the grain boundaries of all magnesium alloys investigated[2] (Fig. 5). These are of similar appearance to those observed by Greenwood, Miller and Suiter[5] in magnesium, copper and alpha-brass which were attributed to condensation of excess numbers of lattice vacancies. It was feared that these cavities could lead to reduction of ductility and thus to premature mechanical failure of magnesium cans, or, if they joined together to form a permeable path, to ingress of the carbon dioxide coolant leading to swelling and bursting of the can as the result of fuel oxidation. Two sets of conditions had to be studied, the creep rates of strain occurring in-pile and the tensile rates obtaining during the pressurizing process when the can is forced into anti-ratchetting grooves in the fuel.

Cavitation at Tensile Rates of Strain

The phenomena have been studied in a series of constant strain rate tensile tests both by metallographic examination and by measurement of density changes.[6] The conditions examined were strain rates of 0.14%/h, 18%/h, 112%/h and 1,075%/h. The temperature range was 20° to 550°C, and the work was carried out on Magnox A12 and on a similar alloy of negligible beryllium content. At the lower temperatures, and the highest rates of strain, transcrystalline cracking and intercrystalline fissures were observed, in addition to the cavities of spherical or elliptical section. The latter were predominant at the higher temperatures. The results and conclusions from this work can be summarized as follows:—

(1) At high rates of strain (Fig. 6) ductility increases continuously with temperature, and although some cavities are formed, these are generally confined to regions near the fracture.

(2) Anomalously low ductilities occur at slower rates of strain in the approximate temperature range 100° to 400°C (Fig. 6). Pronounced and distributed cavitation is present in the middle of the low ductility range; at the ends of this range cavities are confined to fracture regions. Thus where cavitation is severe and generally distributed low ductility values result.

The incidence of cavitation appears to be associated with those temperatures at which severe grain boundary deformation occurs. With increase in temperature crystallites outlining the grain boundaries become resolvable and progressively larger (Fig. 7). The number of cavities increases with the extent of this crystallite formation. At high temperatures, where this is no longer visible, there is no cavitation.

The general trend is made clear by Fig. 8 which compares some further results[6,7] for Magnox A12 with the results originally reported by Greenwood et al.[5] on a magnesium 0.2 wt.% lead alloy. It can be seen that in the case of Greenwood's magnesium-lead alloy, steady increase in elongation to fracture with temperature is interrupted at a temperature near that at which the onset of general cavitation can be detected, and there results a sharp decrease in elongation. This occurs at a lower temperature for lower rates of strain. Thus at a strain rate of 0.2%/h decrease of ductility sets in at 200°C, at 40%/h the same phenomenon occurs at 300°C, at 600%/h no break in the steady increase in ductility with temperature was detected up to 400°C.

Results for the Magnox A12 alloys show very much less marked, but nevertheless similar phenomena for the two strain rates of 0.14%/h and 112%/h. The dependence upon strain rate of the temperature at which ductility ceases to increase is not obvious, as it is in the case of the magnesium 0.2 wt.% lead alloy, but the magnitude of the effect is more marked for the slower strain rate.

Cavitation During Creep

Creep specimens of Magnox A12 were strained to 1% and to 5% in times of 100, 500 and 1,000 h at 200°C and at 400°C.

The results of this work[6] showed:—

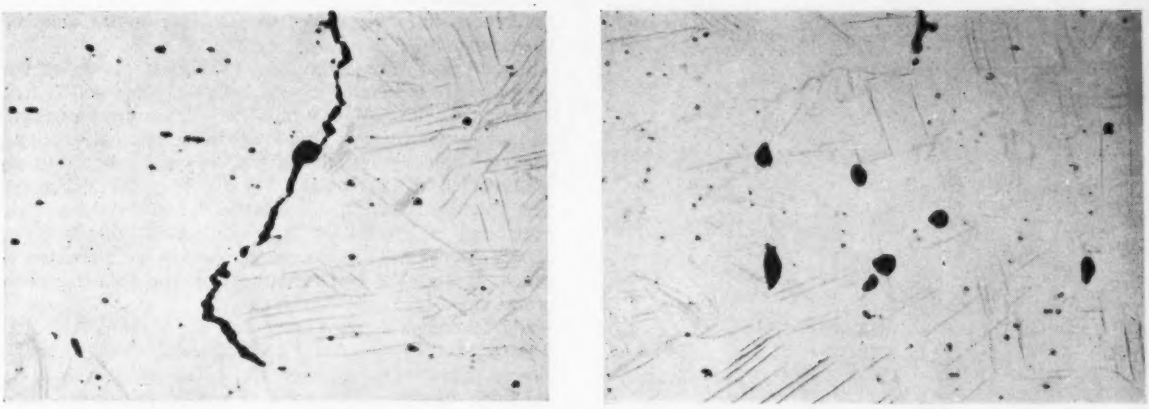


Fig. 5.—Micrographs (x 100) of Be-free A12 (6) creep specimens pre-strained 20% at 500°C.
(a) 1.3 ton/sq. in. 200°C, 3.5% elongation to fracture in 450 hours. (b) 0.1 ton/sq. in. at 400°C, 5% elongation in 100 hours, no fracture.

(1) At constant temperature.
  (a) For a given strain the number of cavities increases with decreasing strain rate.
  (b) For a given strain rate the number of cavities increases with total strain.
(2) No significant difference in cavitation is evident between the two temperatures (200° and 400°C). Few cavities have been detected in other creep specimens strained at temperatures above 400°C, and none in creep specimens strained at 500°C.
(3) Pre-straining in a manner commensurate with that occurring in the anti-ratchetting grooves in the pressurization process does not produce any marked change in the extent of cavity formation.

Some tapered strip specimens of magnesium 1 wt.% aluminium alloy were subjected to creep at 200°C and the results have been used to provide an illustration of the effect of stress and strain on cavitation (Figs. 9 and 10). It can be seen (Fig. 9) that over a wide range of creep strains the density is linearly dependent on strain and also (Fig. 10) that at low stresses the density of cavities is insensitive to stress and at higher stresses there is a rapid increase in the number of cavities formed.

The metallographic features of creep specimens containing cavities are similar to those obtained in tensile specimens, being also temperature-dependent. Distorted grain boundaries and crystallite formation are pronounced at temperatures from 100° to 200°C. At temperatures of 400°C and above, grain boundaries are similar to those of undeformed materials.

The preferential formation of cavities in grain boundaries which are normal to the stress axis is more clearly exhibited in creep specimens than in tensile specimens. The dimensions of cavities in this lateral direction increase with grain size and produce a corresponding reduction in the amount of tertiary creep. Individual cavities rarely exceed 0.005 in. and in a negligible number of cases has there been evidence of the cavities joining together to form long permeable paths. No measurable permeability to argon was detected in any of the specimens.[6]

The source of the cavitation phenomena is obscure. It is now clear that an analogous behaviour is found in a wide range of other alloy systems provided the optimum temperature and strain rate conditions for cavitation are chosen and it is clear that such cavities once formed, can readily grow by the diffusion to them of vacancies arising from mechanical deformation or neutron irradiation. However, no entirely satisfactory explanation of the initiation of the cavities has yet been put forward. Greenwood et al.[5] simply postulated the condensation of vacancies, a mechanism which is unacceptable on surface energy grounds. Crussard and Friedel[8] have proposed a mechanism of nucleation of the cavities arising from blocked dislocations and Gifkins[9] has suggested the formation of jogs at grain boundaries which open up as a result of boundary

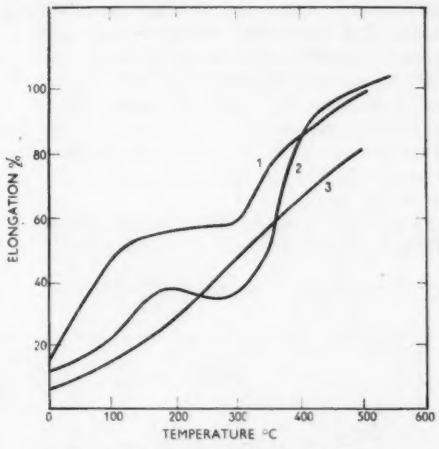


Fig. 6.—Ductility of Magnox A12 (6).
1 Strain rate 18%/hour, as-extruded condition.
2 „ „ 1°% hour, heat-treated „
3 „ „ 1075%/hour, „ „ „

flow and may also grow by vacancy condensation. In the temperature range 100° to 400°C the views advanced by Crussard and Friedel are probably the most satisfactory.

As a by-product of the programme to investigate the incidence of cavitation and the susceptibility to cavitation of a number of possible magnesium canning alloys, data have been obtained on the tensile properties of these magnesium alloys over a wide range of temperatures. Fig. 11 gives the variation of U.T.S. with temperature for pure magnesium, A12 for two different heat treatments, ZW1 and ZA.[6, 10] The grain sizes are given and the strain rates are comparable, so far as the available data permit. It will be seen that broadly speaking the alloys all follow a similar trend, the U.T.S. dropping from the value of 10 to 11 tons at room temperature to 0.5 to 1.5 tons at 400°C. The effect of the two different heat treatments

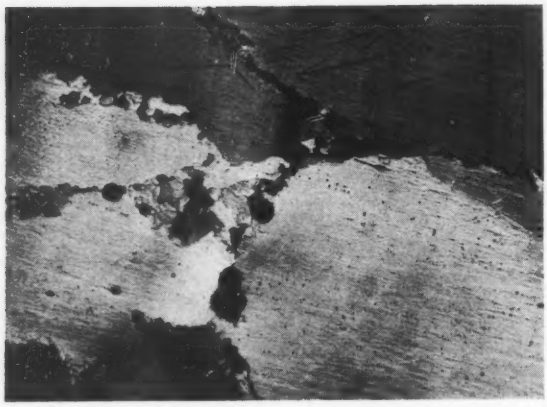


Fig. 7.—Polarized light micrograph (x 100) showing recrystallization at grain boundaries and cavitation (7) of Magnox A12. Strain rate 0.14%/hour at 250°C.

on the A12 alloy decreases with temperature, as might be expected. It should be borne in mind that ZW1 and ZA are both heat-treatable alloys and a range of properties can probably be achieved.

Fig. 12 gives the elongation to fracture for a range of temperatures for ZW1, ZA and A12 at a strain rate of 1,075% per hour.[6] Very high ductilities were obtained for all alloys at these high rates of strain over the temperature range of interest. This is particularly true of the normally fine-grained ZA and ZW1 alloys which exceed 100% elongation to fracture at temperatures above 300°C. Above about 60% elongation the results are very dependent on the manner of deformation and subsequent failure of the specimen; where multiple necking occurs very much greater elongations are recorded. No great significance, therefore, should be attached to the numerical values recorded which are in excess of 60%.

Fig. 13 presents some results of creep tests on Magnox A12,[6] Be-free A12,[6] AM503S,[6] ZA[6] and ZW1[6, 11] at 400°C

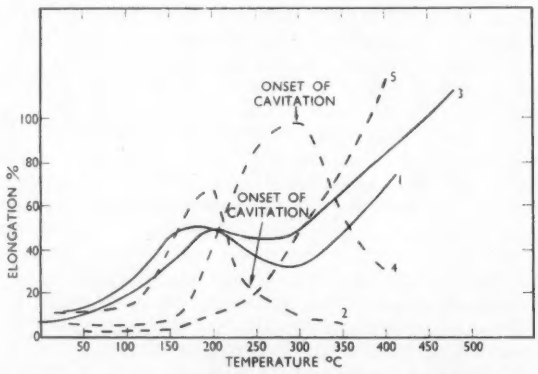


Fig. 8.—Temperature variation of elongation to fracture for Mg-0.2 wt.% Pb alloy (5) and Magnox A12 (6, 7).

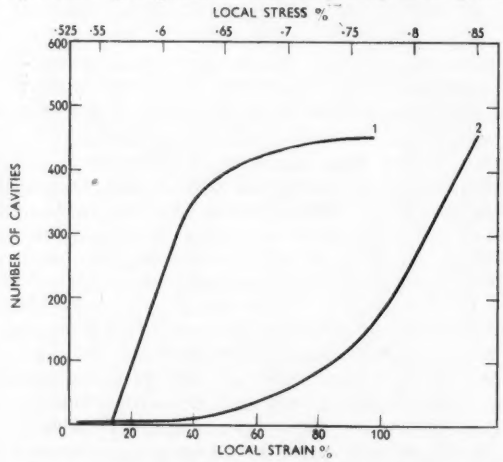
1 Magnox A12 0.14%/hour 3 Magnox A12 112%/hour
2 Mg-Pb alloy 0.2%/hour 4 Mg-Pb alloy 40%/hour
5 Mg-Pb alloy 600%/hour

and 0.16 ton/in.². Curves 1, 2 and 4 are results obtained with ZW1 alloy after three alternative heat treatments and give some indication of the range of values that can be achieved, but in general the ZW1 alloy has the lowest creep strength. There is little or no difference between the two alternative sets of data for AM503S up to 400 h, although a significant difference in elongation to fracture was obtained subsequently.

Fig. 14 gives similar results at 450°C and 0.1 ton/in.² for the same group of alloys.[6] At both 400° and 450°C it is evident that the AM503S possesses higher creep strength and lower elongation to fracture than the alternative alloys. The variation of properties of AM503S with heat treatment is illustrated at 450°C and 0.1 ton/in.² for three different heat treatments in Fig. 15. Curves 1 and 2 have already been used in Fig. 14. Curve 3, data for the chill-cast alloy,[10] indicates the very large increase in creep resistance, which is feasible by variations of the heat-treatment procedure.

Fig. 16 compares some creep data for Magnox A12, ZA, AM503S and Be-free A12 at 200°C and 1.7 ton/in.².[6] The curves show the typical effect of grain size on the high temperature creep properties of magnesium alloys. The mixed grain size ZA alloy (0.025-0.125 mm) has the lowest creep strength and the highest ductility (greater than 60%). The coarse-grained A12 alloy (1 mm) has creep strength equal to that of the AM503S and fractures at ~10% elongation, whilst the relatively fine-grained A12 (0.094 mm) occupies an intermediate position.

The creep strength and ductility of the range of alloys considered are seen to be dependent on heat treatment. The differing heat treatments will produce different grain sizes and different distributions of second phases in the case of the potential precipitation hardening alloys and possibly



Figs. 9 & 10 (combined).—Variation of cavitation with stress and strain for Magnox alloys.

1 Strain curve (lower scale) 2 Stress curve (upper scale)

different pre-precipitation distributions of the solute atoms in cases where the solid solubility is not exceeded such as the aluminium solute in Magnox A12. However, improvements and refinements in properties by variation of the grain size and by variation in the distribution of the addition elements require to be stable for the working life of a can under the temperature and flux conditions existing in pile in order to be of practical value. At present, insufficient is known about these factors and out-of-pile work is proceeding to determine the thermal stability and selected irradiation experiments to assess the in-pile effects.

The low thermal neutron cross-section of magnesium is one of the principal reasons for its selection as a canning material for thermal reactors, and any increase on this cross-section by alloying additions can only be justified if the improvement in life or operating temperature of the

Nuclear Engineering
DATA SHEET
No. 5. Magnesium

Symbol	Mg
Atomic number	12
Atomic weight	24.32

A. PHYSICAL PROPERTIES

Melting point	650°C
Volume expansion on melting	3.97–4.20%
Latent heat of fusion	88.8 cal/g
Boiling point	1,110°C
Latent heat of vaporization	1,300 cal/g
Heat of combustion	145,000 cal/mole

Magnesium has a close-packed hexagonal structure with 2 atoms per unit cell, co-ordination number 12.

Lattice constants at 25°C a=3.2028 Å
c=5.1998 Å
Axial Ratio c/a=1.6235 Å
Atomic diameter=3.190 Å

TABLE A1
Density (19)

Temperature °C	Density g/cm³
20	1.7388
650 (solid)	1.642
650 (liquid)	1,572
700	1.544

TABLE A2
Surface Tension (20)

Temperature °C	Surface tension dynes/cm
681	563
894	502

TABLE A3
Vapour Pressure (21)

Temperature °C	Vapour pressure mm Hg
300	2.5×10^{-5}
380	1.1×10^{-3}
651	2.28
750	12.0
800	26.0
850	49.0
900	94.0
950	166.0
1,000	280.0

TABLE A4
Specific Heat (22)

Temperature °C	Specific heat Cp cal/g, °C
0	0.2413
100	0.2518
200	0.2624
300	0.2729
400	0.2834
500	0.2939
600	0.3045

TABLE A5
Coefficient of Linear Thermal Expansion α for Random Orientation (23)

Temperature range..	20°–100°C	20°–300°C	20°–500°C
$\alpha\times10^6$/°C	25.8	27.0	28.9

Effect of Orientation (24)
Temperature range 15°–35°C
$\alpha_{\parallel}\times10^6/°C=27.1\,\alpha_{\perp}\times10^6/°C=24.3$

TABLE A6
Coefficient of Linear Thermal Expansion $\alpha\times10^6$/°C for Magnesium Alloys

Alloy	Temperature range			
	20°–100°C	20°–200°C	20°–300°C	20°–400°C
A.12 (6)	25.4	26.2	27.0	27.9
Mg/Al (4) (4.36–10.35% Al)	25.4	26.1	27.7	
Mg/Al/Mn (4) (0.1–4.14% Al) (0.27–0.91% Mn)	25.6	26.4	27.2	

TABLE A7
Thermal Conductivity of Magnesium Alloys kcal/sec, cm, °C

Alloy composition	Temperature °C				
	0	100	200	300	400
Magnesium (25)	0.411	0.398	0.389		
Magnox B (27)		0.298	0.320	0.324	0.324
A.12 (6)	0.276	0.288	0.299	0.301	0.323
AM503S (6)	0.352	0.355	0.357	0.360	
ZW1 1.0% Zn.. 0.7% Zr (6)	0.316	0.325	0.334	0.344	
Mg 6% Al (25)	0.190	0.215	0.230		
Mg 8% Al (25)	0.155	0.175	0.190		
*Mg 10.1% Ce (26)		0.253	0.258		
*Mg 2.64% Mn (26)		0.336	0.34		
*Mg 1.8% Mn .. 3.17% Ce (26)		0.285	0.293		

* Values at 50°C and 250°C are plotted in Fig. 3.

Electrical Resistivity of Magnesium (28)
to hexagonal axis 3.77×10^{-6} ohms/cm temperature coefficient 42.7×10^{-4}/°C
to hexagonal axis 4.56×10^{-6} ohms/cm temperature coefficient 41.6×10^{-4}/°C

TABLE A8
Resistivity (Random Orientation)

Temperature °C	Resistivity ohms/cm
0°C	3.9×10^{-6}
100°C	5.56×10^{-6}
300°C	10.0×10^{-6}

Temperature coefficient 42.5×10^{-4}/°C

B. MECHA

Youngs modulus (mod
Shear modulus (modul
Poisson's ratio

Mode

The primary slip plane is the
and 225°C. Above 225°C the p
The twinning plane is (10$\bar{1}$2) and

Tensile Tests on Pur

Temp. °C	U.T. ton/i
R.T.	10.
50	9.9
100	7.4
150	5.8
200	2.2
250	1.7
300	1.1
350	0.7
400	0.4
450	0.2
500	0.2

Each Mg specimen received a h
testing.
Average grain size 0.175 mm (ra

U.T.S. of Magnesium A

Temp. (°C)	A12	Mg, 0.6 0.001
20	9.6	10
50	8.8	10
100		9
150	6.9	7
200	4.5	4
250	3.14	3
300	2.36	2
350	1.61	1
400	1.32	1
450	0.814	0
500	0.558	0
550		0

Elongation to Fra Strain

Temp. °C	A12	Mg, 0. 0.001
20	8	
50	9	
100		
150	34	
200	47	
250	56	
300	55	
350	60	
400	58	
450	57	1
500	47	1
550		1

U.T.S. of Magnesium

Temp. (°C)
R.T.
50
100
150
200
250
300
350
400
450
500

B. MECHANICAL PROPERTIES

modulus (modulus of elasticity)	6.5 $\times 10^6$ lb/in.^{2}
nodulus (modulus of rigidity) ..	2.42 $\times 10^6$ lb/in.^{2}
's ratio	0.35

Modes of Deformation

ry slip plane is the basal plane (0001) and is operative between 20°
Above 225°C the pyramidal secondary slip plane ($10\bar{1}1$) operates.
plane is ($10\bar{1}2$) and the cleavage plane is (0001).

TABLE B1

ensile Tests on Pure Mg at a Strain Rate of 100%/h (6)

°C	U.T.S. ton/in.^{2}	R. of A. %	Elongation to fracture %	L. of P. (ton/in.^{2})
.. ..	10.4	5	7	6.8
.. ..	9.9	10	10	6.4
.. ..	7.4	20	16	4.8
.. ..	5.8	28	29	3.1
.. ..	2.2	40	48	1.18
.. ..	1.7	74	77	1.01
.. ..	1.19	86	91	0.8
.. ..	0.74	65	85	0.57
.. ..	0.48	84	96	0.31
.. ..	0.28	>90	70	0.20
.. ..	0.22	>90	93	0.17

pecimen received a heat treatment of 500°C for 4 h prior to tensile
rain size 0.175 mm (ranging from 0.035 mm to 0.35 mm) after annealing.

TABLE B2

. of Magnesium Alloys at a Strain Rate of 1,075%/h (6)

	U.T.S. (ton/in.^{2})			
A12	Mg, 0.65% Al, 0.0015% Be	Mg, 0.3% Al, 0.008% Be	ZA	ZW1
9.6	10.6	8.6	14.0	14.4
8.8	10.6	10.1	14.6	13.4
	9.2	8.5	9.4	11.0
6.9	7.2	6.4	7.4	8.0
4.5	4.9	4.2	5.0	5.6
3.14	3.2	2.64	4.8	4.0
2.36	2.3	1.25	3.2	2.62
1.61	1.4	1.18	2.3	1.36
1.32	0.73	0.734	1.24	1.05
0.814	0.55	0.45	0.51	0.776
0.558	0.32			
	0.21			

TABLE B3

Elongation to Fracture of Magnesium Alloys at a Strain Rate of 1,075%/h (6)

	Elongation (%)			
A12	Mg, 0.65% Al, 0.0015% Be	Mg, 0.3% Al, 0.008% Be	ZA	ZW1
8	7	7	11	8
9	12	9	14	12
	18	11	26	49
34	23	14	36	62
47	46	31	68	69
56	47	73	62	75
55	58	70	76	75
60	65	89	122	124
58	88	100	142	149
57	104	132	186	123
47	175			
	143			

TABLE B4

S. of Magnesium Alloys at a Strain Rate of 112%/h (6)

Temp. (°C)	U.T.S. (ton/in.^{2})	
	A12	Mg, 0.3% Al, 0.008% Be
.. ..	9.5	10.0
.. ..	9.5	9.4
.. ..	8.2	7.8
.. ..	5.7	4.8
.. ..	3.65	3.4
.. ..	2.62	2.1
.. ..	1.83	1.44
.. ..	1.32	0.90
.. ..	0.73	0.43
.. ..	0.27	0.18
.. ..	0.245	

TABLE B5

Creep Results for Heat-treated A12 (6)

Temp. °C	Stress ton/in.^{2}	Pretreatment of specimen	Time (h) to attain % creep strain								Duration of test (h)	Final strain at fracture %
			0.1	0.2	0.5	1	2	5	10	20		
200	1.25	Heat-treated: at 500°C for 4 h	1	4	280	540	—	—	—	—	1,170	1.65*
200	1.5		—	—	20	73	256	~770	—	—	775	6.0
200	1.75		—	1	3	14	29	145	286	—	286	10.0
400	0.1		11	20	62	133	252	539	880	—	1,150	14.0*
400	0.16		1	4	9	16	28	57	105	171	250	56.0
400	0.022		140	464	—	—	—	—	—	—	1,110	0.29*

* Test in progress.

TABLE B6

Creep Results on Be-free A12 Alloy (6)

Temp. °C	Stress ton/in.^{2}	Pretreatment of specimen	Time (h) to attain % creep strain								Duration of test (h)	Final strain at fracture %
			0.1	0.2	0.5	1	2	5	10	20		
150	2.0	Heat-treated ..	—	1	5	40	149	770	950	—	950	10.0
150	2.25	Heat-treated ..	1	3	7	13	34	252	530	—	530	10.0
200	1.25	Heat-treated ..	5	8	30	150	440	780	—	—	780	5.0
200	1.5	Heat-treated ..	1	4	10	27	96	265	—	—	273	6.0
200	1.75	Heat-treated ..	—	—	—	1	7	32	56	—	56	10.0
200	1.25	As extruded ..	1.5	5	25	52	104	245	437	710	945	42.0
200	1.5	As extruded ..	—	—	2	5	20	70	132	228	300	42.0
200	1.75	As extruded ..	—	<1	2	5	11	30	62	112	153	48.0
400	0.1	Heat-treated ..	20	55	113	344	701	—	—	—	900	2.5*
400	0.16	Heat-treated ..	3	7	15	32	67	122	195	297	392	48.0
400	0.1	As extruded ..	35	245	625	—	—	—	—	—	1,007	0.814*
400	0.16	As extruded ..	30	58	120	185	275	425	550	640	648	24.0
450	0.1	Heat-treated ..	10	20	45	80	142	216	280	330	370	40.0
450	0.08	Heat-treated ..	5	9	30	76	135	250	355	450	456	24.0
450	0.06	Heat-treated ..	5	10	55	300	480	850	1,175	—	1,241	11 5

Grain sizes: As extruded Be-free alloy, 0.0012 in.
Heat-treated Be-free alloy, 0.024 in.
* Test discontinued.

TABLE B7

Creep Results on ZA Alloy (6)

Temp. °C	Stress ton/in.^{2}	Pretreatment of specimen	Time (h) to attain % creep strain								Duration of test (h)	Final strain at fracture %
			1	5	10	15	20	30	40	50		
200	1.75	Heat-treated: 200°C for 20 min, followed by 450°C for 4 h	—	1.9	6.9	9.9	12.4	16.6	20.4	—	27.25	61.25
200	1.5		—	10.5	29.0	51.5	74.5	120.0	—	—	146.0	36.0
250	1.0		0.5	6.0	13.0	19.5	25.3	30.0	—	—	57.0	97.5
250	0.8		—	26.0	53.5	75.5	92.0	108.0	—	—	153.0	80.0
300	0.3		—	102.0	231.0	356.0	454.0	—	—	—	544.0	46.0
350	0.3		—	24.5	55.5	79.0	109.0	167.0	—	—	196.0	35.0
350	0.2		—	44.0	144.0	247.0	342.0	474.0	—	—	574.0	56.0
400	0.16		—	22.0	50.0	67.5	88.5	131.5	—	—	154.0	35.4
400	0.16		—	13.0	26.0	39.5	49.5	71.0	—	—	87.0	36.8
400	0.16		—	19.5	42.0	65.0	89.0	131.0	—	—	227.0	102.0
450	0.1		—	13.0	29.0	52.0	78.0	121.0	—	—	596.0	82.0

Grain sizes: Largest observed 0.14 mm.
Smallest observed 0.020 mm.

TABLE B8

Creep Results on ZW1 Alloy (6)

Temp. °C	Stress ton/in.^{2}	Pretreatment of specimen	Time (h) to attain % creep strain						Duration of test (h)	Final strain at fracture %
			1	5	10	15	20	30		
350	0.3	Heat-treated: 200°C for 20 min, followed by 450°C for 4 h	4	29.5	53.5	87	—	—	360	60
350	0.2		16	75.0	173.0	279	392	—	1,028	64
400	0.16		—	22.5	52	82	110	160	270	88
400	0.1		—	61.0	103.0	—	204	348	729	58

C. NUCLEAR PROPERTIES

TABLE C1

Isotopes

Mass number	Abundance or half life	Particle energy (MeV)
23	β^+ 12s	3.0
24	79%	
25	10%	
26	11%	
27	β^-, γ 10 min	0.84, 1.01
28	β^-, γ 21 h	0.4

TABLE C2

Thermal Neutron Absorption Cross-sections of Magnesium and Likely Additional Elements

Material	cm^2/atom $\times 10^{-24}$	Macroscopic cm^2/cm^3
Be	0.01	0.00123
Mg	0.059	0.00254
Magnox C	0.060	0.00261
Al	0.215	0.013
Mn	13.2	1.0420
Zn	1.06	0.0697
Zr	0.18	0.00765

	Final strain at fracture %
	1.65*
	6.0
	10.0
	14.0*
	56.0
	0.29*

	Final strain at fracture %
	10.0
	10.0
	5.0
	6.0
	10.0
	42.0
	42.0
	48.0
	2.5*
	48.0
	0.814*
	24.0
	40.0
	24.0
	11 5

	Final strain at fracture %
	61.25
	36.0
	97.5
	80.0
	46.0
	35.0
	56.0
	35.4
	36.8
	102.0
	82.0

	Final strain at fracture %
	60
	64
	88
	58

sections of Elements

Macroscopic cm^2/cm^3
0.00123
0.00254
0.00261
0.013
1.0420
0.0697
0.00765

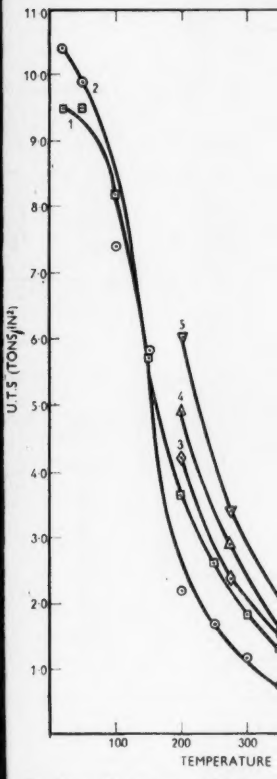


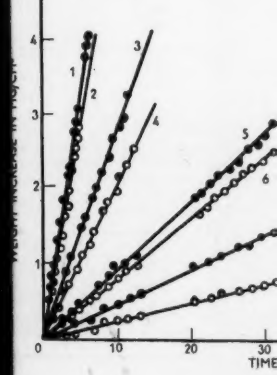
Fig. 11.—Variation of ultimate t
of magnesium alloys with temp

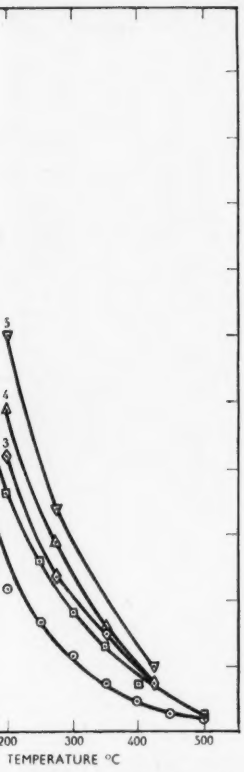
1. A12 heat treated at 400°C for
rate 100%/h (6).
2. Pure Mg (0.175 mm grain si
100%/h (6).
3. ZA (av. grain size < 0.05 mm).
4. A12 (grain size 0.09—0.096 mm
5. ZW1 (av. grain size < 0.05 mm
Heat treatment for 3, 4, 5, 1
Strain rate 420%/h (10).

Fig. 17.—(Right) Increase in i
required with increase in th
cross section relative to Mag

D_c = Irradiation dosage (MWD/t
with Magnox A12.
D_x = Increased irradiation dosage
required to compensate fo
costs due to increased th
cross section X.

1. $D_c = 5{,}000$.
2. $D_c = 3{,}000$.
3. $D_c = 2{,}000$.
4. $D_c = 1{,}000$.





of ultimate tensile strength
ys with temperature (*6, 10*).
d at 400°C for 1 hour, strain
).
5 mm grain size) strain rate

ze < 0.05 mm).
0.09—0.096 mm).
size < 0.05 mm).
t for 3, 4, 5, 1 hour at 400°C.
%/h (*10*).

Increase in irradiation dose
crease in thermal neutron
lative to Magnox A12 (*6*).
dosage (MWD/tonne) achieved
x A12.
radiation dosage (MWD/tonne)
compensate for rise in fuel
o increased thermal neutron
n X.
Dc = 5,000.
Dc = 3,000.
Dc = 2,000.
Dc = 1,000.

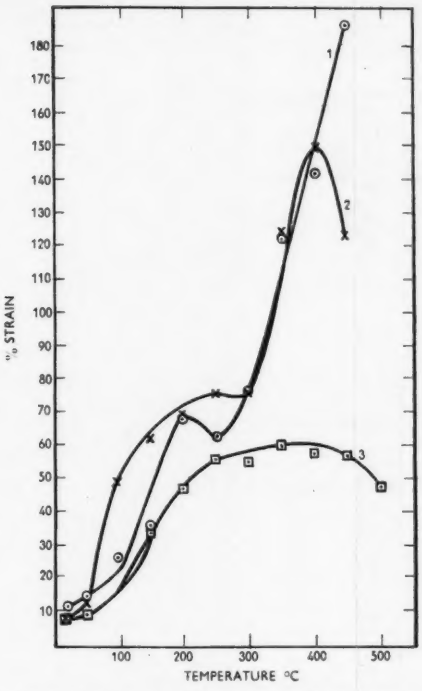


Fig. 12.—Variation of elongation to fracture (*6*) at a strain rate of 1,075%/h.
1. ZA. 2. ZW1. 3. Magnox A12.

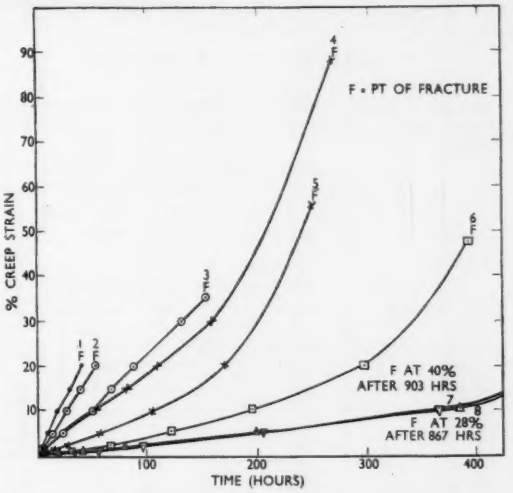


Fig. 13.—Comparison of creep behaviour of magnesium alloys at 400°C and 0.16 ton/sq. in. (*6,11*).
1. ZW1 heat treated 4h at 450°C (*11*).
2. ZW1 heat treated 4h at 510°C (*11*).
3. ZA heat treated { 20 min at 200°C. 4h at 450°C (*6*).
4. ZW1 heat treated { 20 min at 200°C 4h at 450°C (*6*).
5. A12 heat treated 4h at 500°C (*6*).
6. Be-free A12 heat treated 4h at 500°C (*6*).
7. AM503S heat treated 4h at 500°C (*6*).
8. AM503S as extruded (*6*).

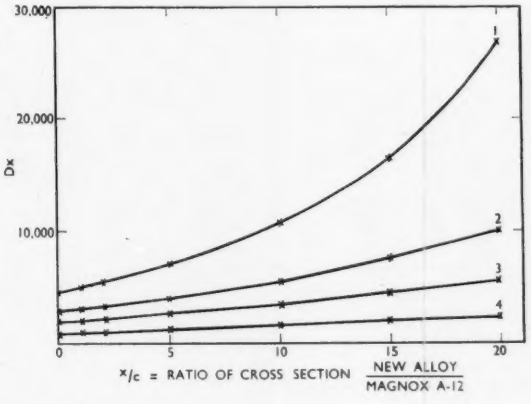
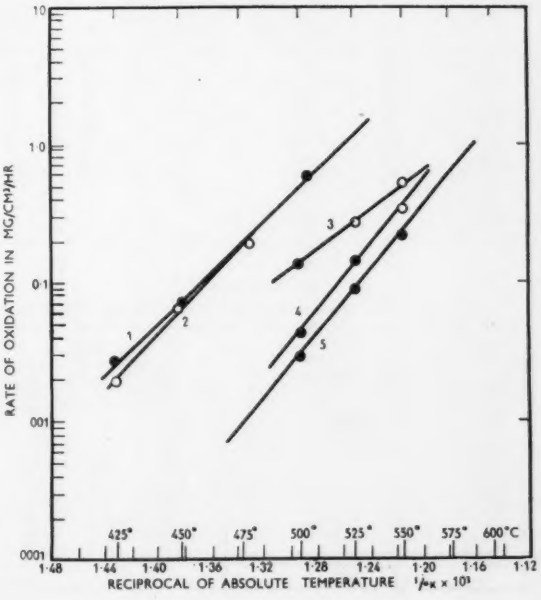


Fig. 19.—Effect of temperature variation on oxidation rates of magnesium alloys (*13*).
1. 0.49% Ni.
2. 0.23% Cu.
3. 2.38% Co.
4. 3.94% Pb.
5. 3.94% Ti.



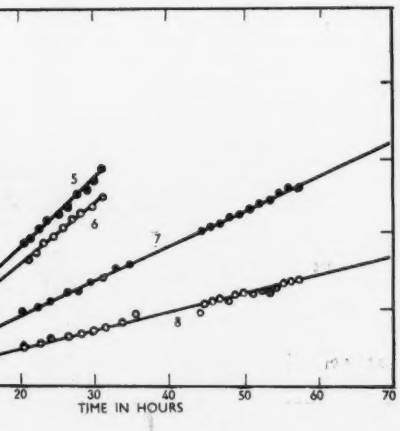
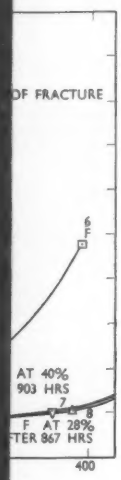


Fig. 18.—(Left) Oxidation rates of rolled pure magnesium in pure oxygen (*13*).
1 and 2. 575°C. 3 and 4. 551°C.
5 and 6. 526°C. 7 and 8. 503°C.



magnesium
11).

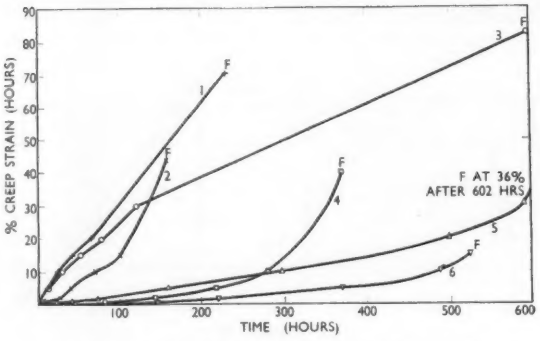


Fig. 14.—Comparison of creep behaviour of magnesium alloys at 450°C and 0.1 ton/sq. in. (*6*).

1. ZW1 heat treated { 20 min at 200°C. 4h at 450°C.
2. A12 homogenized.
3. ZA heat treated { 20 min at 200°C. 4h at 450°C.
4. Be-free A12 heat treated 4h at 500°C.
5. AM503S as extruded.
6. AM503S heat treated 4h at 500°C.

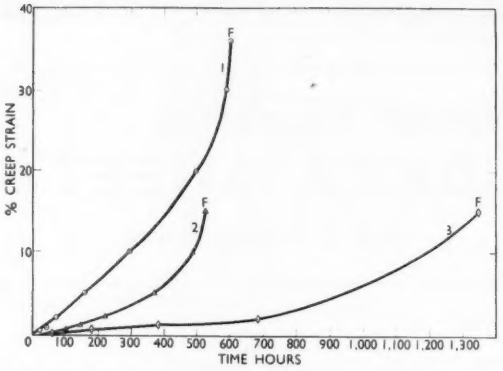


Fig. 15.—Creep behaviour of AM503S at 450°C and 0.1 ton/sq. in. (*6, 10*).

1. As extruded (6).
2. Heat treated for 4h at 500°C (6).
3. In chill-cast form (10).

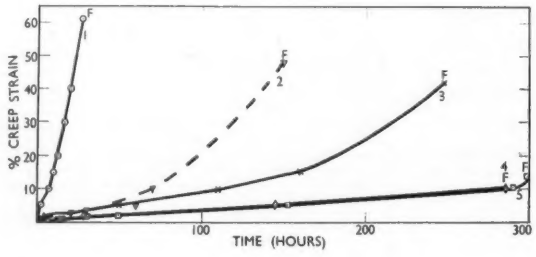


Fig. 16.—(Left) Comparison of creep behaviour of magnesium alloys at 200°C and 1.7 ton/sq. in.

1. ZA heat treated { 20 min at 200°C. 4h at 450°C (6).
2. Be-free A12 as extruded (6).
3. A12 as extruded (6).
4. A12 heat treated 4h at 500°C (6).
5. AM503S (6).

oxidation

Fig. 20.—Effect of temperature variation on oxidation rates of magnesium alloys (*13*).

1. 3.78% Sn.
2. 3.83% Ag.
3. 3.86% In.
4. Rolled pure Mg.
5. 0.006% Fe.

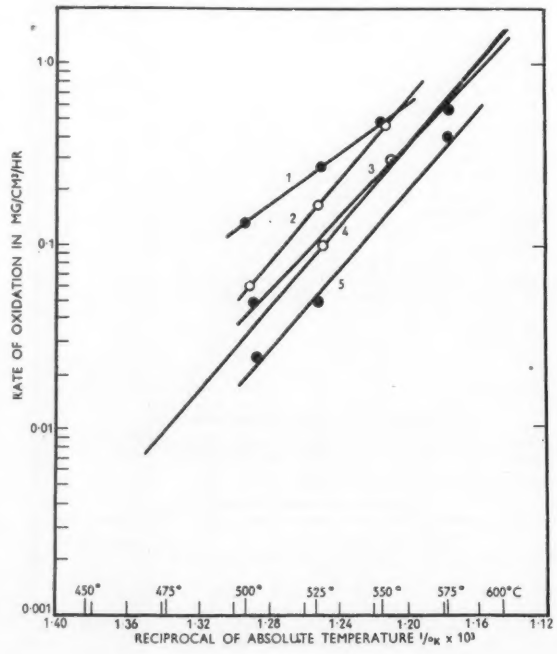
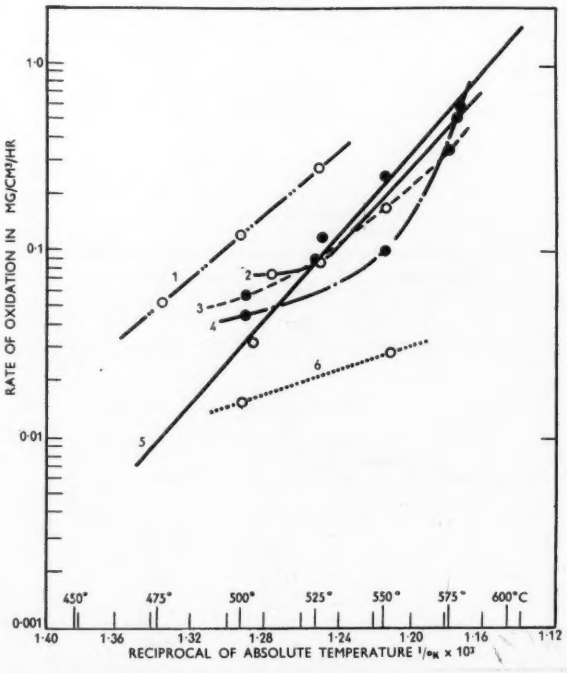


Fig. 21.—Effect of temperature variation on oxidation rates of magnesium alloys (*13*).

1. 3.81% Al.
2. 4.14% Mn.
3. 0.03% Co.
4. 0.21% Si.
5. Rolled pure magnesium.
6. 0.24% Ce+0.32% La.



resulting can more than counterbalance the cost of the increased neutron absorption. The increased burn-up required to compensate for a given increase in cross-section relative to Magnox A12 has been calculated using the method adopted by Moore[12] for a design of the Calder Hall type and the results are given in Fig. 17. It can be seen that for an increase in cross-section by a factor of four, corresponding to the use of aluminium as a canning material, the irradiation dosage of an average cartridge in Megawatt days per tonne of uranium requires to be increased from 3,000 to 3,800 to compensate for the increased fuel costs and, therefore, has to exceed this figure for a net gain. The Magnox A12 alloy with additions limited to $< 1\%$ aluminium and beryllium has a very low cross-section as has the ZA alloy where the addition is limited to zirconium. Values for ZW1 and AM503S are given in Table 1 and are seen to be relatively large. The ratios relative to Magnox are 1.99 and 1.25 respectively. From Fig. 17 to achieve a gain from use of AM503S as a canning material, cartridges capable of 3,000 MWD/te when fabricated in Magnox A12 would have to exceed 3,250 MWD/te.

TABLE 1

Alloy	Cross-section cm^3/cm^3	Cross-section Relative to Magnox A12
ZA	0.00256	~1.0
ZW1	0.00327	1.25
AM503S	0.00520	1.99

COMPATIBILITY

A theoretical survey of the available equilibrium diagrams and other data[6] indicates that magnesium forms, or is likely to form, reduced melting point systems or compounds with all the B sub-group elements of the Periodic system. Similarly, with Group IIA probably Group IIIA, the rare earths, and the third elements in the Group VIII transition metal triads. Elements in Group IV, the alkali metal group, are probably incompatible above 400°C. Elements in Groups IVA and VIIIA are believed to form intermetallic compounds but should be compatible up to the melting point of magnesium. The only sub-groups in which no intermetallic compounds have been reported are the sub-groups VA and VIA and the first element in the Group VIII triads.

Other Metals

Since magnesium will reduce the oxides of all metals except beryllium, thorium, calcium, and some of the rare earths, interdiffusion in the presence of oxide films will depend chiefly on the permeability of magnesium oxide. The likely alloying additions manganese (0.5-1.0%), beryllium (0.005-0.05%), aluminium (~1.0%), zinc (~1.0%), zirconium (0.5-1.0%) are such that the possibility of them significantly affecting the compatibility of magnesium is sufficiently remote to be neglected. Consequently no distinction need be drawn between the compatibility of magnesium and that of AM503S, ZA, ZW1 and the Magnox alloys, including A12. Compatibility with other alloy systems depends much on the structure of the alloy. Elements in dilute solid solution are considerably less active than when concentrated in a second phase, thus nickel is incompatible with magnesium above 510°C, yet stainless steel containing 13% nickel shows no sign of attack by magnesium at temperatures up to 650°C. On the other hand a small quantity of an element such as zinc or silver concentrated at the grain boundaries of the parent alloy may cause considerable damage in contact with a magnesium can. The results of an experimental study of the compatibility of Magnox C with likely contaminant metals indicate that complete penetration of a magnesium can may be expected at the following temperatures for the contaminants listed[2] in Table 2.

TABLE 2

Metal	Penetration temperature
Mercury	Suspect at all temperatures
Tin	Above 200°C
Lead, bismuth	Above 250°C
Cadmium, zinc	Above 300°C
Aluminium, calcium	Above 400°C
Silver, copper	Above 450°C
Nickel, platinum	Above 500°C

The common thermocouple materials, apart from constantan, are all nickel or platinum rich and appear to be very similar in their compatibility to the pure metals. Bearing in mind the necessity to preserve the thermo-electric power unchanged, it would be unwise to use the couples unsheathed in contact with magnesium above 400°C. The most resistant structural materials are plain and alloy steels which are compatible with liquid magnesium.[6] The compatibility of uranium with both solid and liquid magnesium is excellent, there being no evidence of attack after one month at 700°C for the Magnox alloys or for AM503S-type alloys.[6] The solid solubility in thorium is low but two intermetallic compounds are formed, severe attack occurring at 500°C and above. At 400°C no attack occurred in one month.[6]

Gaseous Coolants

The principal reaction in oxidizing gaseous atmospheres is normally the formation of magnesium oxide and useful guidance is given by previous work on oxidation in air and pure oxygen.

The oxidation of a wide range of magnesium alloys in pure oxygen and air has been studied by Leontis and Rhines[13] who found that at low temperatures magnesium formed a protective adherent oxide film. At higher temperatures between 412° and 575°C loose oxide scales were formed and the rate of growth obeyed a linear rate law (Fig. 18). Oxidation rates were slightly more rapid in specimens displaying preferred orientation with the basal planes perpendicular to the surface (Table 3). The presence of water vapour greatly accelerated oxidation, while additions of SO_2 and CO_2 tended to suppress oxidation and were believed to lead to the formation of relatively protective films. At reduced oxygen pressures protective oxidation occurred up to 450°C but above 475°C the rate of growth became linear. There was no evidence that rates of oxidation were sensitive to wide variations of pressure. Leontis and Rhines[13] found that alloying additions in the main decreased the oxidation resistance (Figs. 19, 20 and 21), the exceptions being the cerium and lanthanum alloys which showed a marked increase in oxidation resistance relative to pure magnesium at temperatures greater than 480°C. Nickel and copper are most effective in accelerating oxidation, silver somewhat less so.

Fassell et al.[14] have studied the effect of alloying elements on the ignition temperature of magnesium and find that in general ignition temperatures are lowered by alloying. Their results for pure oxygen at one atmosphere pressure are given in Table 4. Zinc, nickel and bismuth are seen to be most effective in reducing the ignition temperature, the value falling to approximately 500°C from the value of 623°C for pure magnesium. The magnesium aluminium eutectic ignites at 462°C. Calcium and silicon are the only additions producing a rise in temperature. They found the ignition temperature to be pressure dependent; thus, for

pure magnesium in oxygen the ignition temperature falls from 644.5°C at 0.166 atmosphere to 623°C at 1 atmosphere, rises steadily to 645°C at 6 atmospheres and then remains approximately constant. Ignition temperatures must represent a balance between the rate of heat production by oxidation and rate of heat removal, and therefore will depend on the precise experimental arrangement, but the data in Table 4 do give the relative resistance to ignition of the alloys examined.

TABLE 3

Effect of Orientation on the Oxidation of Magnesium at 500°C (13)

Orientation of surface relative to basal plane	Oxidation rate mg/cm².h
Parallel	0.141
Perpendicular	0.184

TABLE 4

Ignition Temperatures of Magnesium and Magnesium Alloys in Oxygen at Atmospheric Pressure (14)

System	Composition, % alloying element	Ignition temperature °C	Physical state of alloy
Pure Mg	—	623	Solid
Mg Al	5.88	527	Solid
	18.17	502	Solid and liquid
	63.15	462	Liquid
Mg Ag	9.04	537	Liquid and solid
Mg Bi	10.0	500	Solid
Mg Cd	61.4	517	Liquid and solid
Mg Co	1.0	617	Solid
	5.0	616	Solid
Mg Cu	10.3	537	Liquid and solid
	20.5	519	Liquid and solid
Mg Ca	5.0	633	Liquid
Mg In	20.0	593	Liquid
Mg Li	4.0	513	Solid
Mg Mn	2.0	616	Solid
Mg Ni	5.0	510	Liquid and solid
	20.0	508	Liquid and solid
Mg Sb	5.22	588	Solid
Mg Si	3.15	625	Solid
Mg Sn	11.34	556	Solid
Mg Pb	16.24	575	Liquid and solid
	58.26	504	Liquid and solid
Mg Zn	9.25	509	Liquid and solid

Carbon Dioxide

The possible carbon dioxide magnesium reactions either with pure carbon dioxide or in the presence of carbon monoxide and/or water vapour are too complex to allow satisfactory predictions of service behaviour to be made.

Experimental work at 400°C in dry carbon dioxide at 8 atmospheres pressure has shown that the minimum weight gain occurred in pure magnesium, this gain increasing progressively through the alloys Magnox C, AM503S, ZT1, ZRE1, Magnox E and sintered magnesium powder. Pure magnesium and the first two alloys had weight gains of approximately 0.1 mg/cm²/5 months. The other alloys ranged from 0.15 to approximately 1.0 mg/cm²/5 months. The effect of moisture (0.15 wt.%) was to increase the rate of weight gain by an average factor falling from four in the first month to two after two months.[2]

In such experiments the weight changes determined experimentally by exposure to dry or moist carbon dioxide represent a balance between the loss of magnesium vapour and the deposition of carbon, the formation of magnesium oxide or of magnesium carbonate. They are, therefore, difficult to interpret but nevertheless serve as a guide to the degree of interaction occurring. Where feasible metallographic examination leading to an actual measurement of the loss of section is more satisfactory and allows detection of localized pitting.

Recent work on the Magnox A12 alloy conducted on this basis[6] has shown that even at 500°C the mean rate of loss of section in 8 atmospheres pressure of dry carbon dioxide is 0.0002 in. in four months with occasional pitting of maximum depth 0.002 in. There is evidence, not yet fully

Les Applications Nucléaires du Magnésium et de ses Alliages

Les alliages de magnésium présentent potentiellement un attrait pour les réacteurs de type Calder Hall principalement par suite de leur coupe thermique réduite d'absorption de neutrons et de leur excellente compatibilité avec l'uranium. L'alliage Magnox A.12 couramment employé comme une matière pour récipients doit convenir à la production à grande échelle et sa qualité doit être uniforme, il faut aussi qu'il puisse être donné les formes appropriées, être scellé et comprimé. On s'attend ensuite à ce qu'il fonctionne comme enveloppe extensible pouvant se déformer sans se briser dans la mesure requise par le gonflement du combustible uranium. Finalement, il faut aussi que l'alliage possède une résistance au cheminement de température suffisamment élevée pour que les surfaces de transfert de chaleur conservent leur profil sous la pression du courant de gaz réfrigérants et une résistance suffisante à l'attaque par le réfrigérant et ensuite par l'eau de la mare de refroidissement pour empêcher la pénétration par ces mécanismes. Pour les réacteurs à puissance plus élevée, la ductilité à faible température et la résistance de cheminement de température élevée ont besoin d'être améliorées, mais on croit que cela pourra être obtenu par le contrôle de la grosseur du grain et par la modification des additions d'alliage. On y exprime l'idée que la température supérieure limite d'opération des alliages d'aluminium sera déterminée par le différentiel de sécurité nécessaire entre les températures de fonctionnement et d'ignition plutôt que par d'autres propriétés.

Die Nutzung von Magnesium und seinen Legierungen im Gebiet der Atomkraft-Verwertung

Magnesium Legierungen sind wegen der Moeglichkeiten, die sie bieten, von erheblichem Interesse fuer Reaktoren vom Calder Hall Typ, in erster Linie, weil sie einen niedrigen Absorptions-Querschnitt fuer langsame (thermische) Neutronen haben, ferner ausgezeichnet sich mit Uranium vertragen. Die Legierung Magnox A.12, die zur Zeit als Huelsen-Werkstoff Verwendung findet, muss fuer die Produktion im grossen Masstab geeignet sein ohne Aenderung der Qualitaet, muss die Faehigkeit haben, in passende Formen verarbeitet zu werden, dichten Abschluss gewaehrleisten und unter Druck gesetzt werden koennen. Es ist weiter erforderlich, dass man mit ihr eine sich dehnende Huelse herstellen kann, die sich deformiert, ohne Risse zu entwickeln, soweit dies durch das Schwellen des Uraniums als Brennstoff noetig wird. Schliesslich muss die Legierung auch bei hohen Temperaturen eine genuegende Kriechfestigkeit haben, sodass die zur Waerme-Uebertragung dienenden Flaechen ihre Form unter dem Druck des Kuehlgas-Stromes beibehalten und nicht durch das Kuehlmittel und spaeter durch das Wasser im Kuehlsumpf angegriffen werden, um einen Einbruch in die verschiedenen Mechanismen zu verhindern. Fuer Reaktoren mit hoeherer Einheitsleistung wird eine Verbesserung der plastischen Verformbarkeit bei niedriger Temperatur und der Kriechfestigkeit bei hohen Temperaturen noetig werden, jedoch glaubt man, dass man dies durch eine Kontrolle der Korngroesse und durch eine Aenderung der Legierungs-Zusaetze erreichen kann. Es wird die Ansicht vertreten, dass die obere Temperatur-Grenze fuer das Arbeiten mit Magnesium-Legierungen eher dadurch bestimmt wird, dass man einen Sicherheitsbereich zwischen Betriebs- und Entzuendungstemperaturen haben muss, als durch irgendwelche andere Eigenschaften.

Las Aplicaciones Nucleares de Magnesio y sus Aleaciones

Las aleaciones de magnesio son potencialmente atractivas para los reactores del tipo de Calder Hall, principalmente debido a su sección transversal de baja absorción neutrónica térmica y a su compatibilidad excelente con el uranio. La aleación Magnox A.12, actualmente empleada como un material envasador, tiene que ser adecuada para la producción en gran escala con cualidad consistente, capaz de fabricación en formas convenientes, sellándose y presurizándose. Luego se le exige que funcione como una envoltura extensible deformando sin fractura a la extensión exigida por el hinchamiento del uranio combustible. Finalmente, la aleación también debe poseer una resistencia de arrastre de temperatura suficientemente elevada para que las superficies de transferencia de calor retengan su perfil bajo la presión de la corriente de gas enfriador y suficiente resistencia al ataque por el enfriador y subsecuentemente por el agua de depósito de refrigeración para impedir penetración por estos mecanismos. Para los reactores de régimenes más elevados, la ductilidad de baja temperatura y resistencia de arrastre de alta temperatura necesitan ser mejoradas, pero se cree que esto pueda ser conseguido mediante control de tamaño de grano y modificación de los agregados de aleación. Se expresa el punto de vista que la temperatura limitadora superior de funcionamiento de aleaciones de magnesio será fijada por la necesaria diferencial de seguridad entre las temperaturas de funcionamiento y encendido más bien que por otras propiedades.

confirmed, that the pits are due to localized attack and do not increase in depth after the first month. Considered from the point of view of rate of loss of section of magnesium alloy cans the limiting upper temperature of operation is at least 450°C. Ignition tests of Magnox alloys[2] revealed an ignition temperature of approximately 640°C under 11 atmospheres pressure of carbon dioxide, no ignition occurred in flowing carbon dioxide at 1 atmosphere pressure with a flow rate of 20 ft³/h up to 700° C.

Hydrogen

The solubility of hydrogen in magnesium is high, rising from 10 cm³ (N.T.P.) per 100 g at 200°C to 18 cm³ (N.T.P.) per 100 g at 600°C. No reliable diffusivity data appear to be available. The rate of absorption will be accelerated by the dissociation of molecular hydrogen to the atomic state, brought about by the intense neutron and gamma fluxes occurring in the vicinity of the fuel elements of a reactor. It appears extremely unlikely, therefore, that magnesium cans would prove sufficiently impermeable to protect a uranium metal fuel from attack by hydrogen. Ceramic fuels, stable in the presence of hydrogen, require operating temperatures above those possible with magnesium and the metal is, therefore, generally unsuitable for hydrogen-cooled reactors.

Aqueous Media

Magnesium is the most electro-negative of the fabricated industrial metals and thus suffers anodic attack whenever it is in contact with other metals in the presence of an electrolyte. This property is, in fact, used in the cathodic protection of ship's hulls and buried pipelines and cables where slabs of magnesium are fastened, so as to make electrical contact, to the part being protected. When a conducting medium such as sea-water or damp earth has completed the circuit current will flow and the magnesium anodes will be preferentially attacked thus protecting the more noble metal of the couple.

Commercially pure magnesium, when not in contact with other metals, is no more prone to corrosion attack than mild steel under normal atmospheric conditions and adequate methods exist for its protection. When considering the protection of magnesium by means of a blanket film, e.g. painting, it is of prime importance to recognize that its oxide layer is chemically active and unlike aluminium oxide will combine with water to give an alkaline solution which quickly destroys a normal paint film and causes flaking. Thus when applying such a protective coating the metal should be first prepared by chromating and then painted immediately afterwards, or it should be given a sealing coat by a suitable resin process to preserve the surface of the metal.

TABLE 5
Effect of Galvanic Couples with Magnox C (Results of 70 day Tests) (2)

Couple material	Location	
	Pond	Laboratory
Blank run, no couple	A few shallow pits	Good condition. No pitting. Some white deposit on surface
Stainless steel ..	Small shallow pits in couple region	No pitting apparent. White deposit on surface
Mild steel	Heavy pitting in couple area	Extensive shallow pitting concentrated in couple region. Red deposition on steel
Aluminium	Good conditions. Region near couple protected	Good condition. Magnox appears to be protected. Some pitting on outside edge of Magnox
Sintered aluminium powder	No pitting	Thick white deposit over specimen and couple. No pitting
Graphite	Small shallow pits extending over whole surface, particularly concentrated in couple region	Some white deposit, some pitting but not severe

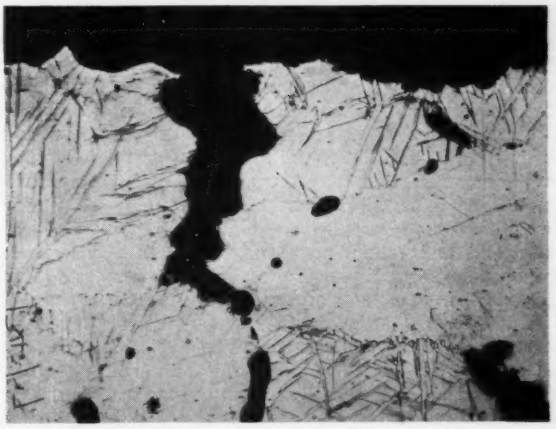


Fig. 22.—Effect of intergranular cavitation on cooling pond corrosion in untreated water (6).

At Calder, irradiated Magnox-canned cartridges are stored underwater in cooling ponds for a period in order to allow the intensely active, short-lived fission products to decay. During this period, any severe corrosion of the magnesium alloy would result in penetration of the thin can wall and exposure of the uranium fuel to aqueous corrosion. The resulting leaching of fission product activity into the pond would produce serious problems of active effluent disposal. Investigations in the laboratory and on site have determined the factors which influence the rate of corrosion of the Magnox series of alloys and it has been shown that, in the absence of galvanic couples, corrosion can be almost completely suppressed to adjusting the pond water to pH > 11 by the addition of caustic soda, and by restricting the concentration of chlorides and carbonates which are the principal common accelerating ions. Thus in an untreated domestic water the corrosion rate of Magnox was found to be 2.0 mg/cm²/month, whereas in a controlled and treated supply the rate was reduced to 0.04 mg/in.²/month.[6]

The effect of galvanic couples has been studied primarily in the Windscale cooling ponds, but also in the laboratory in pond water and has included studies of the effect of metallic couples and heat treatment on model cans in Magnox A12 and Magnox E and C.

The results of the tests of Magnox C, which typify behaviour of the Magnox alloys, are given in Table 5 and show that, particularly where active couples occur, there is some danger of perforation of the can.[2]

Studies have also been made with the Magnox A12

(i) with a carbon/magnesium oxide surface film formed by carbon dioxide reaction at high temperature;
(ii) in a heavily worked condition;
(iii) containing grain boundary cavitation produced by straining at creep rates of deformation.

The first two conditions lead to transgranular pitting and the third to intergranular attack (Fig. 22). (ii) and (iii) will necessarily occur in irradiated cartridges and the rate of pitting in untreated water would then be high enough to cause extensive perforation on the can walls during the cooling period.

FABRICATION

Magnesium alloys can be fabricated as castings (sand, gravity die, pressure die) and as forgings, extrusions or

sheet, the choice of method depending mainly on the nature of the component. The various cast and wrought magnesium alloys exhibit no important differences in their machining characteristics. There is a greater tendency for ribbon-shaped swarf to form with wrought alloys than with cast material owing to the greater toughness and elongation of the former. Otherwise the cutting pressure, surface condition, cutting temperature, etc., are approximately the same for all alloys, so that the same cutting speeds and the same tools can be used, irrespective of the alloy and the condition of the material. For a given power of machine, normal speeds for magnesium are tenfold those for steel and twice those for aluminium alloys.

Currently the Magnox A12 cans of Calder Hall-type reactors are fabricated by casting billets which are extruded to solid bars, given an homogenizing heat treatment, then bored and machined to final form. Constant efforts are being made to reduce the cost of can production but these considerations are always subject to the need for reliability under operating conditions, the high cost of possible pile shut-downs outweighing production economies obtained at the cost of reduced reliability. Development work is in hand on impact extruded hollow tubes, which are subsequently fin rolled to their final form.

The need to insist on a high degree of reliability has led to the setting of very high inspection standards for flux inclusions and other defects in the material. To implement these standards maximum use has been made of established inspection methods and laboratory work is currently in hand on the development of improved methods. Due to the low contrast between the base magnesium alloy and likely flaws or inclusions, X-ray methods of inspection are not sufficiently sensitive. Inspection is carried out by

TABLE 6
Tensile Tests at 20°C on Magnesium Alloys (17)

Magnesium alloy	Irradiated or unirradiated	Yield stress 10^3 lb/in.^{2}	Ultimate tensile strength 10^3 lb/in.^{2}	Elongation %
A12	Unirradiated	16.0	21.2—21.3	5.3— 6.2
	Irradiated	17.8	22.1—23.0	5.3
Be-free A12..	Unirradiated	15.4—17.8	21.1—22.7	5.3— 7.1
	Irradiated	15.4—16.0	21.2—21.9	6.6
AM503S ..	Unirradiated	23.8—24.5	30.7—32.3	3.5— 4.0
	Irradiated	24.7—25.6	27.7—29.9	1.8— 2.2
ZA	Unirradiated	18.1	26.0—26.3	5.8— 6.2
	Irradiated	18.7	19.5	0.8
ZW1 ..	Unirradiated	22.5—25.6	31.9—32.0	12.4—15.9
	Irradiated	23.0—23.3	30.5—31.8	16.8—17.6

examination of macro sections and by ultrasonic methods at the billet and bar stages of the production process and finally by detailed visual inspection of the finished cartridge.

Welding

Magnesium may be welded by the argon arc process, by the oxy-acetylene gas method or by electrical resistance welding. The argon arc process does not suffer from the residual flux difficulties of the oxy-acetylene method, is applicable to all alloys and offers a greater variety of permissible joint designs and has, therefore, tended to supersede the other methods. The major factor determining the liability to crack during welding is the solidification range. Additions of 0.15% calcium are stated to lower the solidus 15° to 55°C below the normal value for alloys to which it is added[15] and experimental work has shown that a low calcium content is necessary for weldability and has led to the elimination of the calcium contained in the earlier Magnox alloys.[2] Metallographic investigation has shown that weld cracking in the Magnox series of alloys is due in part to the formation of brittle intergranular films and for maximum weldability, suppression of the formation of second phases as intergranular films is necessary. Of the other alloys of interest magnesium zirconium and magnesium manganese alloys have good weldability while the weldability of magnesium cerium alloys is improved by the presence of aluminium, which suppresses the formation of grain boundary films of $CeMg_9$ by the preferential formation of $CeAl_2$ as small discreet particles in the over-heated zone adjacent to the weld.[16]

Automatic argon arc equipment has been developed for the welding of the Magnox A12 cartridges which are then helium filled, sealed, and subsequently any leaking cartridge is detected by search for helium with a mass spectrometer. The overall efficiency of current welding procedures, and of current cartridge manufacturing and inspection methods, has been demonstrated by the very low number of can failures occurring during the first year of operation of the first Calder reactor.

EFFECTS OF REACTOR CONDITIONS

Reactor conditions differ from the out-of-pile experimental work in the presence of high thermal and epithermal fluxes and intense gamma radiation plus some fission fragment bombardment of the inner surface of the can. It is also the case that the reaction with the carbon dioxide coolant may be modified under pile operating conditions due to the presence of active species arising from the reaction of the carbon dioxide molecules with the high neutron and gamma fluxes. It is believed that apart from the existence of charged carbon dioxide molecules there will also be present charged carbon monoxide molecules, oxygen atoms and charged and uncharged oxygen and ozone molecules.

Effect of Irradiation on Mechanical Properties

In view of the importance of magnesium cans retaining their ductility to discharge their function as extensible envelopes, the effect of irradiation on ductility has been investigated by Makin and Minter.[17] The irradiation experiments were carried out at the lowest practicable temperature (40° to 50°C) in an attempt to avoid annealing effects. The alloys examined were A12, Be-free A12, AM503S, ZA and ZW1. Irradiation was carried out to an integrated dose of 10^{20} neutrons per cm^2 and tensile tests were carried out at 20°C and 100°C at a strain rate of 0.72% per hour both on irradiated specimens and on control specimens held at the same temperature for the same time. The results are summarized in Tables 6 and 7 and indicate no significant difference in yield stress, ultimate tensile strength or elongation to fracture. The integrated dose of $\sim 10^{20}$ neutrons per cm^2 is known to produce a marked hardening in other metals. Makin and Minter, therefore, concluded that annealing of irradiation hardening occurred at the irradiation temperature 40° to 50°C. Since recovery from irradiation damage occurs at appreciably lower temperatures than recovery from cold

TABLE 7
Tensile Tests at 100°C on Magnesium Alloys (17)

Magnesium alloy	Irradiated or unirradiated	Yield stress 10^3 lb/in.^{2}	Ultimate tensile strength 10^3 lb/in.^{2}	Elongation %
A12	Unirradiated	9.5—14.1	16.2—16.3	14.1—16.7
	Irradiated	12.8—13.2	16.8—16.9	13.7—14.1
Be-free A12..	Unirradiated	12.0—12.3	18.7	8.0—19.8
	Irradiated	12.0—12.6	16.7—16.8	13.2—17.6
AM503S ..	Unirradiated	16.6—16.7	17.0—17.6	13.2
	Irradiated	15.8—17.7	18.2—19.7	8.0— 9.3
ZA	Unirradiated	10.7—11.8	15.0—15.4	10.6
	Irradiated	12.2—14.2	16.7—17.6	11.5—13.2
ZW1 ..	Unirradiated	15.3	20.7	36.1
	Irradiated	15.6—15.8	20.6—21.2	43.6—54.4

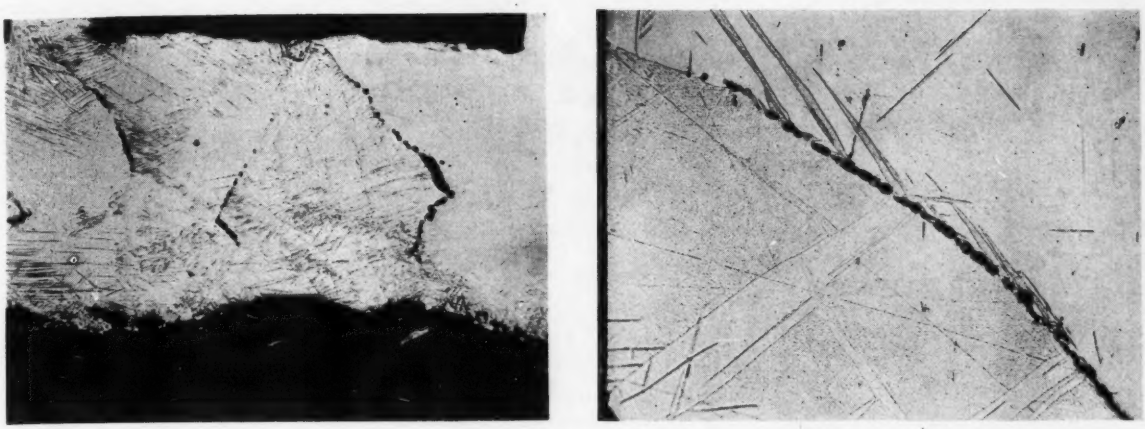


Fig. 23.—Cavitation in Magnox C cartridges after irradiation in Windscale (*18*) for one year at 4.2 x 10^{12} n/cm² epithermal flux.
(a) Temperature 100°C, total irradiation 316 MWD/tonne, small burst. (b) Temperature 120°C, total irradiation 300 MWD/tonne, no burst.

work in nickel and iron, then this finding is, perhaps, not surprising in view of the low recovery temperature of cold-worked magnesium and magnesium alloys. In-pile work is required to confirm that there is no change in the actual presence of the neutron flux. No change was found in the microstructure and it was, therefore, inferred that magnesium alloys in the absence of stress are not subject to cavitation.

Examination of experimental Magnox C cartridges irradiated in the Windscale piles has shown fairly extensive cavitation at the grain boundaries of cans which have been subjected to significant strains from both the bowing and swelling of uranium bars.[18] Fig. 23 shows extreme examples of cavitation at grain boundaries. The work suggests, as does the work of Makin and Minter,[17] that strain is necessary for cavitation to occur even in the presence of intense neutron fluxes. There was no conclusive evidence that the incidence of cavitation was enhanced by the irradiation, although it seems unlikely that lattice vacancies arising from displacement of magnesium atoms from their sites by fast neutron collision should fail tc cause some increase in the extent of cavitation.

Examination of irradiated cans from the Calder Hall reactors has not produced any evidence to suggest that there is a significant increase in the rate of reaction with the carbon dioxide due to the presence of active species.

Apart from the stable naturally occurring isotopes of mass numbers 24, 25 and 26, magnesium forms isotopes of mass numbers 27 and 28 by neutron capture. These unstable isotopes decay with the emission of gamma radiation with half lives of 10 min and 21 h respectively. Only radio isotopes for which the product gamma activity times concentration is high, are of importance from the point of view of subsequent handling and calculation shows that only the isotope of mass number 27 needs consideration in this context. The saturation activity for this isotope for a flux of 10^{11} neutrons/cm²/sec is 0.35 millicuries per gram which is relatively low, compared with other possible canning materials. Aluminium, for example, will give 13 millicuries per gram and stainless steel of the order of 60 millicuries per gram. The relatively low activity and the short half life of 10 min combine to make magnesium an attractive material from the handling point of view.

General Remarks

Available evidence suggests that magnesium alloys cans still have a margin of performance in hand to allow their utilization as canning materials for reactors operating at outlet gas temperatures in excess of the current proposed maximum of 400°C. It is probable that improvements in mechanical properties, in particular ductility at 200°-300°C and creep strength at 400°-500°C are still possible, while the compatibility with carbon dioxide is unlikely to prove a limiting factor at temperatures significantly below 500°C. The upper limit of safe operation of magnesium alloy cans of future reactors is thus likely to be determined by the necessity to establish a safe margin between the maximum working temperature and the ignition temperature in order to ensure that no reactor transient can lead to ignition.

Acknowledgments

The author is grateful to Sir Leonard Owen, Managing Director, and Mr. L. Rotherham, Director of Research and Development, Industrial Group, United Kingdom Atomic Energy Authority, for permission to publish this paper. He is also grateful to many of his colleagues in the Industrial Group, particularly in the Culcheth Laboratories, for permission to use their previously unpublished results and to Atomic Energy divisions of the Parsons and General Electric companies for similar courtesies.

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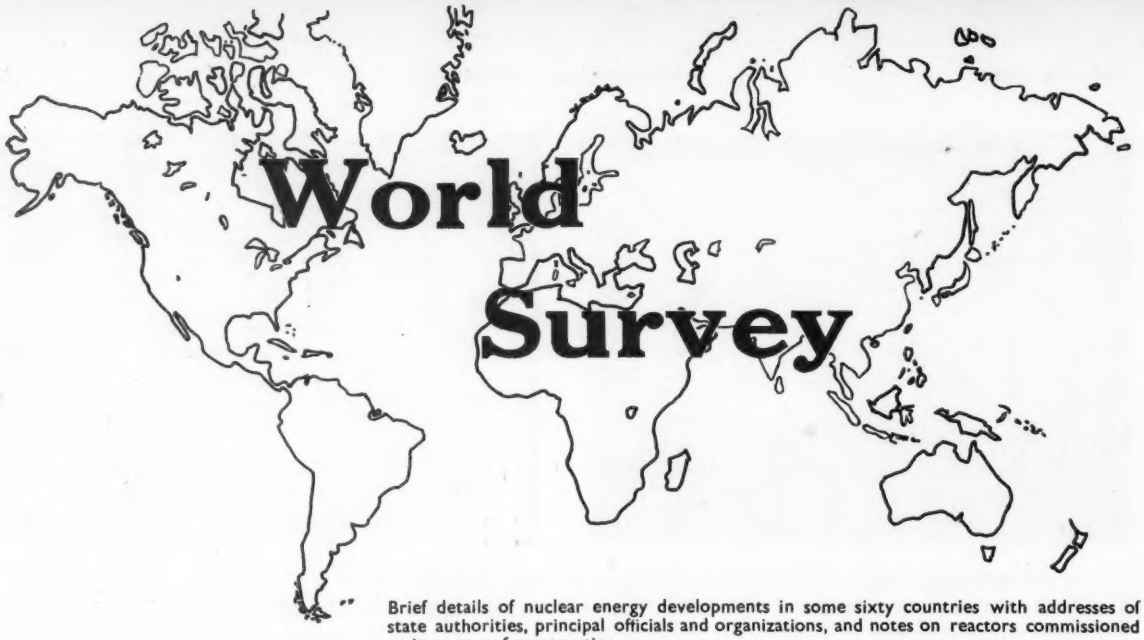


World Survey

Brief details of nuclear energy developments in some sixty countries with addresses of state authorities, principal officials and organizations, and notes on reactors commissioned or in course of construction.

Argentine

Comision Nacional de la Energia Atomica:
Avenida del Libertador General San Martin 8250, Buenos Aires, Argentina.
Established: May 31, 1950.
President: Capt. O. A. Quihillalt.
Members: Dr. T. R. Isnardi, Dr. J. B. Collo, Commander J. M. Rubio, Snr. E. E. Galloni, Dr. A. G. Dominguez.
Reactors:
Pool-type research reactor ordered from General Electric (U.S.A.) for installation at Buenos Aires.

Australia

Australian Atomic Energy Commission:
45 Beach Street, Coogee, New South Wales.
Established: 1953.
Chairman: Sir Jack Stevens, K.B.E., C.B., D.S.O.
Deputy Chairman: Prof. J. P. Baxter, O.B.E., B.Sc.
Commissioner: H. M. Murray, B.Sc.
Reactors:
HIFAR, 10 MW DIDO-type at Lucas Heights due to become critical mid-1958.

Austria

Oesterreichische Atomenergie Kommission:
Bundeskanzleramt, Auswärtige Angelegenheiten, Ballhausplatz 2, Vienna 1.
Chairman: Dr. H. Haymerle.
Sektionsrat: Richard Polaczek.
Principal Organizations: Oesterreichische Studiengesellschaft fuer Atomenergie, Lenaugasse 10, Vienna 8.

Belgium

Commission Nationale Pour L'Etude de l'Utilisation Pacifique de l'Energie Nucleaire (CNEUPEN):
23 Square de Meeûs, Brussels.
Telephone: Brussels 11 46 30.
Established: January 7, 1956.
Chairman: Jean Rey, Minister of Economic Affairs.
Vice-Chairmen: Pierre Ryckmans, Commissioner for Atomic Energy; P. de Groote, Administrator, Study Centre for Nuclear Energy.
Principal Organizations: Institut Interuniversitaire des Sciences Nucleaires, 11 Rue d'Egmont, Brussels. Centre d'Etudes pour les Applications de l'Energie Nucleaire (CEAEN), 31 Rue Belliard, Brussels.
Reactors:
BR1—natural uranium, air cooled, graphite moderated research reactor similar to BEPO, developing 3.5 MW (thermal).
25 MW test reactor ordered from Nuclear Development Corp.
11.5 MW (E) PWR ordered from Westinghouse by Societe Co-operative Nucleaire.

Bolivia

Observatorie de Fisica Cosmica:
Chacaltaya.
Director: Prof. E. Scobar.

Brazil

Comissao de Energia Nuclear:
350 Avenida Marechal Camara, Rio de Janeiro.
Established: November, 1956.
Chairman: Admiral Octailio Cunha.
Members: Otavio Augusto Dia Carneiro, J. Costa Ribeiro, Joao Maffei, Bernhard Geisel, Francisco Humberto.
Principal Organizations: Instituto de Energia Atomica, Sao Paulo.
Reactors:
5 MW pool-type research reactor being installed at Sao Paulo University by Babcock and Wilcox.
10 MW BWR ordered by American and Foreign Power Co. from General Electric.

Bulgaria

Institute of Nuclear Physics:
Academy of Science, Sofia.
Director: Prof. G. Manadjakov.
Reactors:
2 MW research reactor using natural uranium supplied by U.S.S.R.

Burma

Union of Burma Atomic Energy Centre:
c/o Union of Burma Applied Research Institute, Kanbe P.O., Rangoon, Burma.
Telephone: Rangoon North 167 and North 544.
Cable Address: Uburatence.
Director: Hla Nyunt.
Advisory Committee: Maung Maung Kha, Freddie Ba Hli.
Technical Consultants: San Tha Aung, Soon Sein.
Departmental Heads: Soe Win, Cho Cho, Sein Win, Htin Nyo, Sein Mg Win.
Burma is adopting a two-step atomic energy development programme. **First step**—establishment of a nuclear radiation laboratory. This should be completed by the end of 1958. **Second step**—small training and research reactor programme, probably by 1960-61.

Canada

Atomic Energy of Canada, Ltd.:
Chalk River, Ontario.
Cables: Mota.
President: W. J. Bennett, O.B.E., B.A., LI.D.
Directors: D. W. Ambridge, C.B.E., B.Sc.; J. S. Duncan, C.M.G.; G. A. Gaherty, B.E., LI.D.; A. R. Gordon, O.B.E., Ph.D., F.R.S.C.; R. L. Hearn, B.A.Sc., D.Eng.; H. Massue, D.App.Sc., P.Eng., M.E.I.C.; V. W. Scully, C.M.G., F.C.A.; F. C. Wallace, D.S.O., M.C.
Officers: D. A. Keys, Ph.D., D.Sc., F.R.S.C., Scientific Adviser to the President; W. B. Lewis, C.B.E., Ph.D., F.R.S., Vice-president, Research and Development; J. L. Gray, M.Sc., Vice-president, Administration and Operations; D. G. Campbell, C.A., Treasurer; D. Watson, M.A., Secretary.
Principal Organizations: Canadian General Electric Company; Hydro-Electric Power Commission of Ontario; A.M.F. Atomics (Canada), Ltd.
Reactors:
40 MW NRX experimental reactor (reconstructed in 1952).
200 MW NRU high flux reactor became critical on November 3, 1957.
20 MW NPD-2 being constructed as prototype for a full-scale power reactor.
PTR—pool test reactor—a 100-watt unit for testing reactivity of fuel samples.
ZEEP—research reactor for lattice studies at Chalk River. Went critical in 1945.
5 MW pool-type research reactor under construction at McMaster University, Hamilton.

C.E.R.N.

Conseil Européen pour la Recherche Nucléaire:
Meyrin, Genève 23.
Telephone: Genève 34 20 50. 32 09 30.
Telegram: Cernlab-Genève.
President: M. Francois de Rose (France).
Vice-Presidents: J. Willems (Belgium), Prof. W. Heisenberg (Germany).
Committee Members: Prof. E. Amaldi (Italy), J. H. Bannier (Netherlands).
Member Countries: Belgium, Denmark, France, German Federal Republic, Greece, Italy, Netherlands, Norway, Sweden, Switzerland, United Kingdom and Yugoslavia.
Programme: CERN is mainly concerned with research on high-energy particles. A 600 MeV synchro-cyclotron is due to come into operation in 1958 while assembly of a 25 GeV proton synchrotron will start next year.

Chile

Comision Chilena de Energia Atómica:
Ministero de Relaciones Exteriores, Santiago, Chile.

China

Academica Sinica:
3 Wen Tsin Chien, Peking.
Reactors:
2 MW swimming pool research reactor being supplied by U.S.S.R. for installation near Peking.

Colombia

Instituto de Asantos Nucleares:
Bogota, Columbia.

Cuba

Comisión de Energia Nuclear de Cuba:
Paseo de Marti No. 212, Apartado 2471, Havana.
Secretary: Dr. Marcelo Alonso.
Reactors:
10 MW power reactor to be installed by the American and Foreign Power Co., owners of the subsidiary Cia. Cubana de Electricidád.

Czechoslovakia

Eustav Jaderne Fysity:
Husinec-Rez, Prague 5.
Telephone: Prague 925410.
Director: Eng. Ch. Cestmir Simane.
Reactors:
2 MW 10% enriched uranium swimming pool research reactor from U.S.S.R., commissioned September, 1957.
Projected 150 MW natural uranium heavy water moderated power reactor at Banska Bystrica.

Denmark

Danish Atomic Energy Commission:
Christiansborg Ridebane 10, Copenhagen K, Denmark.
Telephone: Minerva 5433.
Cable Address: Atomkom.
Established: December 21, 1955.

Chairman: Prof. Niels Bohr, D.Phil. et Sc. et Techn.
Vice-Chairman: Prof. Robert Henriksen.
Chairman of Executive Committee: Mr. H. H. Koch, Permanent Under-Secretary of State.
Commission Members: Dr. K. A. Bak, Director, Copenhagen Gas and Electricity Services; H. P. Christensen, Director, Elsinore Shipyard; G. Hartz, Director, Thomas B. Thrige; Prof. Robert Henriksen, Director, North Sealand Power and Tramway Co. Ltd.; Eiler Jensen, President, Confederation of Danish Trade Unions; Prof. S. Tovborg Jensen, Royal Veterinary and Agricultural High School; Prof. Tage Kemp, D. med., University Institute for Human Genetics; H. H. Koch, Permanent Under-Secretary of State; Niels Munck, Civil Engineer; Jens Moller, Director, Vestkraft Power Co.; Maersk McKinney Möller, Shipowner; Ivar Nörgaard, Principal, Esbjerg High School; Pedar Nörgaard, Director, Stjernen Breweries; Mogens Pagh; Prof. Axel Pedersen, Royal Veterinary and Agricultural High School; Prof. Ebbe Rasmussen, D.Phil., Royal Veterinary and Agricultural High School; Prof. R. E. H. Rasmussen, D.Phil., Technical University of Denmark; Prof. Poul Brandt Tehberg, D.Phil. et Med., University of Copenhagen; H. Stevenius-Nielsen, Director, Federation of Danish Industries; Haldor Topsoë, Civil Engineer; Prof. Sven Werner, D.Phil., Institute of Physics, University of Arhus.
Departmental Heads: Prof. I. C. Jacobsen, Head of Research; Prof. T. Bjerge, Head of Administration, Risoe Research Establishment; Mr. Chr. L. Thomsen, Head of Secretariat.
Principal Organization: Society for the Industrial Utilization of Atomic Energy (Danatom), Strandvej 102, Hellerup.
Reactors:
Danish Reactor No. 1 (DR1) 500 W homogeneous solution research reactor by Atomics International. Commissioned August 15, 1957.
DR2. 5 MW enriched uranium light water moderated and cooled tank type research reactor by Foster Wheeler Corp., U.S.A.
DR3. 10 MW enriched uranium heavy water materials testing reactor, PLUTO type, by Head Wrightson Processes Ltd.

Dominican Republic

Comision Nacional de Investigaciones Atomicas:
Universidad de Santo Domingo (Alma Mater), Apartado 232, Ciudad Trujillo.
Telephone: Ciudad Trujillo 94472, 2754, 5412.
Established: January 7, 1957.
Chairman: Coronel Henry D. Lopez-Penha.
Secretary General: Mayor Radiologo Rafael B. Gonzalez M.
Commission Members: Dr. Jose G. Soba, Sr. R. Paino Pichardo, Coronel Medico Dr. Francisco Gonzalez Cruz, Sr. Abelardo Elias Achecar, Sr. Pedro M. de Vargas Santana, Dr. Otto Gonzalez, Ing. Emil Boyrie de Moya, Sr. Miguel A. Cestero and Ing. Petronio Mejia Read.
Departmental Head: Administrative, Sr. Dimitry I. Pavloff.
Reactors:
Project for 13 MW (E), PWR from Martin Co., U.S.A.

E.A.E.S.

European Atomic Energy Society:
Secretary: Dr. B. Goldschmidt, 69 Rue de Varrene, Paris 7.
Established: June, 1954.
Member Countries: Belgium, Denmark, France, Germany, Italy, Holland, Norway, Portugal, Spain, Sweden, Switzerland and United Kingdom.
Purpose: Informal discussions on nuclear energy.

Egypt

Egyptian Atomic Energy Commission:
National Research Council, Dokki, Cairo.
Telephone: Cairo 804930.
Established: February 17, 1955.
Chairman: Major Kamal El Din Hussein.
Reactors:
2 MW (thermal) pool-type reactor in course of construction near Cairo. Supplied by U.S.S.R.

Eire

Atomic Energy Committee:
45 Merrion Square, Dublin.
Telephone: Dublin 62371.
Established: March, 1956.
Chairman: D. McAleese.
Secretary: John Lennon.
Members: J. Conroy, E. J. Conway, Lt.-Gen. M. J. Costello, H. Hall, M. A. Hogan, J. J. McHenry, P. G. Murphy, T. E. Nevlin, E. T. Walton.

Euratom

European Atomic Energy Community:
c/o European Coal and Steel Community, Place de Metz, Luxembourg.
Established: January 1, 1958.
President: M. Louis Armand (France).
Vice-president: Signor Enrico Medi (Italy).
Members: M. P. H. de Groote (Belgium), Herr H. Krekeler (Germany), Mr. E. N. Ja Sassen (Netherlands).
Programme:
Installation of 15,000 MW of nuclear power stations in member countries (France, Germany, Belgium, Italy, Netherlands, Luxembourg) by 1967.

Finland

Atomic Energy Board:
Ministry of Commerce and Industry, Hallituskatu, 4, Helsinki.
Telephone: Helsinki 14311.
Established: October 25, 1956.
Chairman: Prof. Erkki Laurila.
Vice-Chairman: Director-General Heikki Lehtonen.
Secretary General: Martti Mutru.
Commission Members: Mr. Erkki Kinnunen, Mr. H. Frilund, Mr. A. I. Virtanen, Mr. Wm. Lehtinen, Mr. A. Solin, Mr. J. Salin.
Principal Organizations: Tampella Oy, Tampere; A. Ahlström Oy, Varkaus; Atomienergia Oy.
Reactors:
Sub-critical assembly ordered in June, 1957, by Volmayhdistys Ydin for research and training.

France

Commissariat a l'Energie Atomique:
69 rue de Varenne, Paris 7ème.
Telephone: Invalides 66-45 à 47. Invalides 86-60 à 63.
Cables: Energet-Paris.
Established: October 18, 1945.
Administrator General: M. Pierre Guillaumat.
High Commissioner: M. Francis Perrin.
Commission Members: Pierre Ailleret, Roger Belin, J. Coulomb, G. Devaux, General Lavaux, L. Leprince-Ringuet, Y. Rocard and F. de Rose.
Principal Organizations: Auxi-Atome, 11 rue de la Pepiniere, Paris, 8; C.A.R.A. (Compagnie d'Applications et de Recherches Atomiques), 45 Avenue Kleber, Paris, 17; Compagnie Francaise des Minerais d'Uranium, 6 Avenue Gourgaud, Paris 17; Conservatome, 18 rue Seguin, Lyon, Rhone; France-Atome, 6 Boulevard Haussman, Paris; Indatom, 48 rue de la Boetie, Paris; Societe Centrale de l'Uranium et Minerais et Metaux Radioactifs (SCUMURA), Hotel de la Chambre de Commerce, 4 Boulevard Trudaine, Clermont Ferrand, Puy de Dome; Societe Industrielle et Miniere de l'Ouest (S.I.M.O), Lieu de l'Usine, l'Ecarpier, Loire-Infre; Societe Intertechnique, Division Nucleaire (Dassault), 94 Avenue de Paris, Versailles; Societe pour les Applications Techniques dans le Domaine de l'Energie Nucleaire (SATNUC), 45 Boulevard de la Gare, Paris; Societe Industrielle de Combustible Nucleaire (S.I.C.N.), Usine S.A.C.M. à Annecy; Mines de Bitume et d'Asphalte du Centre (S.M.A.C.), 41 Avenue Montaigne, Paris; Propatome.
Reactors:
Research: ZOE, Fontenay-aux-Roses, E.L.2., Saclay; 15 MW E.L.3, high flux heavy water, Saclay; Aquilon, critical facility for heavy water lattice studies, Saclay; Prosperine, small homogeneous unit, Saclay; Triton, Fontenay-aux-Roses; Melusine, Grenoble; Minerve, Saclay.
Pu and Electricity Production, Marcoule: G.1, 5 MW (E); G.2 and G.3, 30 MW (E). Chinon: E.D.F.1 60 MW (E) and E.D.F.2, 100-200 MW (E).
Propulsion: Q-244.

German Democratic Republic

Nuclear Research Institute:
Neubrandenburg, Mecklenburg, Dresden.
Director: Prof. Manfred von Ardenne.
Reactors:
2 MW water-moderated, 10% enriched U235, research reactor at Rossendorf, near Dresden. Supplied by U.S.S.R. Went critical, December 16, 1957.
Project for a 100 MW experimental power reactor at Mecklenburg. To be supplied by U.S.S.R.

German Federal Republic

Bundesministerium fuer Atomfragen:
Bad Godesberg, Luisenstrasse 46.
Telephone: 5891-95.
Established: January 26, 1956.
Minister for Atomic Affairs: Prof. Dr.-Ing. Siegfried Balke.
Commission Vice-presidents: Prof. Dr. Leo Brandt, Prof. Dr. Otto Hahn, Prof. Dr.-Ing. Karl Winnacker.
Members: Dr. Hermann J. Abs, Dr. Hans C. Boden, Prof. Dr. Ernst von Caemmerer, Dr. Rupprecht Dittmar, Dr.-Ing. Richard Fischer, Gerhard Geyer, Dr. Hans Goudefroy, Prof. Dr. Ulrich Haberland, Prof. Dr. Otto Haxel, Prof. Dr. Werner Heisenberg, Prof. Dr. Gerhard Hess, Dr.-Ing. Carl Knott, Dr. Wilhelm Alexander Menne, Prof. Dr. Friedrich A. Paneth, Dr.-Ing. Alfred Petersen, Dr. Hermann Reusch, Dr.-Ing. Hans Reuter, Prof. Dr. Wolfgang Riezler, Ludwig Rosenberg, Prof. Dr. Arnold Scheibe, Dipl.-Ing. Heinrich Schöller, Prof. Dr. Gerhard Schubert, Dipl.-Ing. Georg Schulhoff, Dr.-Ing. Hermann Winkhaus.
Principal Organizations: Kernreaktor Bau- und Betriebs-Gesellschaft mbH, Karlsruhe; Rheinisch-Westfälische-Elektrizitätswerk A.G. (R.W.E.); Siemens-Schuckertwerke A.G., Erlangen; Brown Boverie and Co. A.G., Mannheim; Friedrich Krupp, Essen; Farbwerke Höchst, A.G., Frankfurt; Degussa A.G. Frankfurt; Society for the Application of Nuclear Energy to Shipping, Hanover.
Reactors:
1 MW pool-type research reactor at Munich. Went critical October 23, 1957. Supplied by A.M.F.
Under construction: 1 MW pool type at Hamburg (Babcock and Wilcox, U.S.A.); 50-100 kW water boiler units at Frankfurt and Berlin (Atomics International, U.S.A.); 2 MW Merlin at Düren (A.E.I.—John Thompson); 10 MW DIDO (Head Wrightson Processes); 10 MW NRX, natural uranium research reactor (Karlsruher Reaktor Bau- u. Betriebs, GmbH.).
Project for a 15 MW homogeneous, gas-cooled graphite-moderated power reactor at Dusseldorf.

Greece

Greek Atomic Energy Commission:
14 Patriarch Toachim Street, Athens.
Established: September, 1954.
Chairman: A. Spanidis, Rear Admiral.
Vice-Chairman: J. Pantazis, Professor, University of Athens.
Secretary General: Th. G. Kouyoumzelis, Professor, University of Athens.
Commission Members: Twenty-two, representing the University of Athens, the Technical University, the University of Salonica, National Defence Staff and different Ministries.
Reactors:
1 MW swimming pool research reactor ordered in January, 1957, from A.M.F. of New York. Due to go critical at the end of 1958.

Guatemala

Comision Energia Atomica:
6th Avenida, Entre 5 y 6 Calle, Zona 1.
Director: Senor Ricardo Diaz.

Hungary

Orszagos Atomenergia Bizottsag:
Budapest, Hungary.
Established: January 20, 1956.
President: Antal Apro.
Vice-Presidents: Arpad Kiss (administrative), Lajos Janossy (scientific).
Commission Members: Rezsö Bognár, László Bezoki, Richard Kolos, István Kovács (1). Lénárd Pál, János Sebestyén, F. Bruno Straub, Karoly Virag, Károly Simonyi, Sandor Szalai, István Kovács (2).
Secretary of Committee: Lajos Jánossy.
Reactors:
2 MW (thermal) swimming pool research reactor, being built by the U.S.S.R., is due for commissioning mid-1958.
Low-capacity research reactor is to be built by the U.S.S.R. at Debrecen, Eastern Hungary.

I.A.E.A.

International Atomic Energy Agency:
Konzerthaus, 20 Lotheringstrasse, Vienna 3.
Established: October 1, 1957.
Director-General: W. Sterling Cole.
Board of Governors: Comprises representatives from 23 member countries.
Programme:
To foster development of peaceful uses of atomic energy in the 80 countries which are members of the agency.

India

Department of Atomic Energy:
Apollo Pier Road, Bombay, 1.
Telephone: Bombay 35058.
Cables: Atomerg.
Established: August 3, 1954.
Minister: Shri Jawaharlal Nehru.
Chairman, A.E.C. and Secretary to Government: Dr. H. J. Bhabha, D Sc., F.R.S.
Member, A.E.C.: Dr. K. S. Krishnan, B.Sc., F.R.S.
Joint Secretary: Shri V. M. Parulekar.
Controller, A.E. Establishment: Shri E. C. Allardice.
Geological Adviser: Dr. D. N. Wadia, D.Sc., F.R.S.
Principal Organizations: Tata Institute of Fundamental Research, Bombay; Indian Institute of Science, Bangalore Institute of Nuclear Physics, Calcutta University.
Reactors:
100 kW swimming pool research reactor, Apsara, at Trombay. Went critical August 4, 1956.
Canadian NRX reactor at Trombay, expected to become critical this year.
Zerlina, zero energy reactor with natural uranium fuel, heavy water moderated; under construction.

Indonesia

Director for Internal Economic Relations:
Indonesian Foreign Ministry, Thajeb.

Israel

Atomic Energy Commission:
P.O. Box 7056, Hakirya, Tel-Aviv.
Telephone: Tel-Aviv 68410.
Estaolisned: 1952.
Chairman: Dr. Ernst David Bergmann.
Members: Dr. Israel Dostrovsky, General Jacob Dori, Dr. Saul Cohen, Prof. Joel Rakah, Prof. Samuel Sambursky.
Reactor:
1 MW pool-type research reactor ordered from A.M.F.

Italy

Comitato Nazionale per le Ricerche Nucleari (C.N.R.N.):
Via Belisario, 15 Roma.
Telephone: Roma 460.900, 462.912, 470.614, 474.504, 474.507, 478.673.
Cable Address: Nucleare Roma.
Established: June 26, 1952.
Chairman: Sen. Prof. Basilio Focaccia.
Vice-Chairmen: Prof. Edoardo Amaldi, Prof. Ing. Arnaldo M. Angelini.
General Secretary: Prof. Ing. Felice Ippolito.
Commission Members: Prof. Vincenzo Caglioti, Dr. Ing. Franco Castelli, Prof. Bruno Ferretti, Prof. Enrico Medi, Comm. Dr. Guido Giorgi, Prof. Antonio Carrelli.
Departmental Heads: Dott. ssa Annetta Baroni, Ing. Umberto Belliazzi, Ing. Aldo Forcella, Rag. Guglielmo Mennella, Dr. Carlo Polvani, Dr. Aldo Santinelli, Ing. Franco Silvestro.
Principal Organizations: S.E.N.N., Via Savoia 15, Rome. S.E.L.N.I., c/o Edison, Via Foro Buonaparte 31, Milan. S.O.R.I.N. (Societa Ricerche Impianti Nucleari), Via Turati 8, Milan. Agip Nucleare, Via G. Passarella 2, Milan.
(Two further groups, S.I.M.E.A. and S.O.M.I.R.E.N., are controlled by Agip Nucleare.)
Reactors:
CP-5 (DIDO-type) materials testing research reactor under construction for C.N.R.N. at Varese by A.C.F. with engineering services by Vitro Corp. Due for completion mid-1958.
Projected 134 MW pressurized-water reactor to be built by S.E.L.N.I. and Westinghouse.
Projected 200 MW gas-cooled graphite moderated power reactor to be built by Agip Nucleare in association with N.P.P.C.
Projected 150 MW pressurized-water power reactor to be supplied to S.I.M.E.A. by Vitro. Tenders called for 150 MW nuclear power station by S.E.N.N.
50 KW water boiler ordered by Politecnico of Milan from Atomics International. Swimming pool reactor for S.O.R.I.N. being supplied by A.M.F.

Japan

Atomic Energy Commission:
2-2 Kasumigaseki, Chiyoda-ku, Tokyo, Japan.
Telephone: Tokyo (58) 2585.
Established: January 1, 1956.
Chairman: Matsutaro Shoriki.
Commission Members: Ichiro Ishikawa, Yoshio Fujioka, Hiromi Arisawa, Kankuro Kaneshige.
Departmental Head: Yoshitake Sasaki (director, Atomic Energy Bureau, The Science and Technics Agency).
Principal Organizations: Mitsubishi Atomic Power Committee, Higashi No. 9, 2-6, Marunouchi, Chiyoda-ku, Tokyo. First Atomic Power Industrial Group, Tokyo-Boeki-Kaikan, 1-2 Ote-machi, Chiyoda-ku, Tokyo. Nippon Atomic Energy Industrial Group, Daiichi-Bussan, 1-2, Tamuracho, Siba, Minato-ku, Tokyo. Sumitomo Atomic Energy Commission, Sumitomo-Building, 5-22 Kitahama Higashi-ku, Osaka. Atomic Industrial Conference, Hitachi-Seisaku-Syo, 1-4 Marunouchi, Chiyoda-ku, Tokyo.
Reactors:
Solution type (water boiler) research reactor by Atomics International went critical on August 27. Heavy-water enriched uranium tank type (CP-5) research reactor being built by A.M.F. Atomics. Heavy-water natural uranium tank type research reactor under construction by Japanese manufacturers.

J.E.N.E.R.

Joint Establishment for Nuclear Energy Research (JENER):
P.O. Box 175, Lillestrom, Norway.
Telephone: Lillestrom 71 25 60.
Cables: Atomenergi, Oslo.
Reactor:
JEEP—a 700 kW (thermal) natural uranium, heavy water research reactor at Kjeller.

J.I.N.R.

Joint Institute for Nuclear Research (JINR):
Dubna, Moscow.
Established: March 26, 1956.
Director: Prof. Dimitri Blokhintsev.
Assistant Directors: Dr. M. Donyz (Poland), Dr. Vacia Votruba (Czechoslovakia).
Member Countries: Albania, Bulgaria, China, Czechoslovakia, East Germany, Hungary, Mongolia, North Korea, Poland, Rumania, U.S.S.R., Viet-Nam.

Mexico

Universidad Nacional Autónoma de México:
Justa Sierra No. 16, Mexico.
Director: Dr. Manuel Sandoval Vallarta.
Reactors:
10 MW power reactor ordered from General Electric (U.S.A.) for installation by American and Foreign Power Co.

Nepal

Ministry of Foreign Affairs:
Katmandu, Nepal.

Netherlands

Reactor Centrum Nederland (RCN):
Scheveningseweg 112, The Hague.
Telephone: The Hague 514581.
Cable Address: Reactorholland.
Established: July 6, 1955.
Chairman: Dr. H. M. Hirschfeld.
Vice-Chairman: Dr. E. L. Kramer.
Director General: Prof. Dr. J. M. W. Milatz.
Commission Members: Prof. Dr. J. M. W. Milatz (director), Dr. Ir. R. Houwink (technical director), Dr. W. Reyseger (administrative director).
RCN is a consortia of some fifty Netherlands industrial concerns.
Reactors:
100 kW swimming pool research reactor at Delft Technical University. Manufacturer: A.M.F. Commissioned: May, 1957.
20 MW high flux Oak Ridge research reactor at Petten. Ordered from A.C.F.
Zero-energy suspension research reactor ordered from K.E.M.A. Laboratories, Arnhem.

Norway

Norwegian Atomic Energy Committee:
Ministry of Industrial Affairs, Oslo, Norway.
Telephone: Oslo 410050.
Principal Organizations: Noratom A.S., Oslo.
Reactors:
Natural uranium, boiling heavy water reactor for experimental purposes supplying steam to an adjoining pulp factory at Holden.

O.E.E.C.

Organisation for European Economic Co-operation:
2, rue André Pascal, Paris XVIème.
Telephone: Tro 46 10/74 30.
Steering Committee for Nuclear Energy:
Chairman: Prof. Leander Nicolaidis (Greece).
Vice-Chairmen: Pierre Guillaumat (France), Friston C. How, C.B. (U.K.).
Study Group for the Chemical Processing of Irradiated Fuels:
Chairman: Erich Pohland (Germany).
Rapporteur: Erik Haeffner (Sweden).
Study Group on Experimental Reactors:
Chairman: Sigvard Eklund (Sweden).
Rapporteur: Lew Kowarski (C.E.R.N.).
Working Group on Nuclear Power Stations:
Chairman: Franco Castelli (Italy).
Working Parties:
—**Administrative and Financial Regime of Joint Undertakings:**
Chairman: Jens Chr. Hauge (Norway).
—**Security Control:**
Chairman: Bertrand Goldschmidt (France).
—**Trade:**
Chairman: Carl Swartz (Sweden).
—**Training:**
Chairman: Robert Major (Norway).
—**Public Health and Safety:**
Chairman: Reidar Eker (Norway).
—**Third Party Liability:**
Chairman: Adrian D. Belinfante (Netherlands).
Insurance Sub-committee:
Chairman: Jacques Basyn (Belgium).
O.E.E.C. Nuclear Energy Secretariat: General Counsel: Pierre Huet. Consultants: Einar Saeland, Marc Dumont, Jerry Weinstein, Karl Wolff.
Principal Organizations: Eurochemic is being formed to operate a chemical processing plant at Mol, Belgium, for the treatment of natural and slightly enriched uranium. Capacity: 100 tons per year. European Atomic Energy Agency will come into operation this year.
Reactors:
Project for a homogeneous aqueous reactor to be built at Winfrith Heath, Dorset.

Pakistan

Atomic Energy Commission:
Victoria Road, Karachi.
Established: January, 1955.
Chairman: Dr. Nazir Ahmed.
Commission Members: Dr. Salimuzzaman Siddiqui (Director of Scientific and Industrial Research); Dr. Raziuddin Siddiqui (Vice-Chancellor, Peshawar University); Dr. M. O. Ghani (Agricultural Development Commission for Government of East Pakistan); Dr. M. H. Toosy, Prof., Nishtar Medical College.
Reactors:
Medium power research reactor in West Pakistan. Due for completion next year.
Power reactor in East Pakistan.

Peru

Junta de Control de Energia Atomica:
Lima, Peru.
Director: General Don Jorge Sarmiento.

Philippines

Nuclear Energy Commission:
c/o National Economic Council, Padre Faura Street, Ermita, Manila, Philippines.
Telephone: Manila 5-70-91.
Established: Interdepartmental Committee on Atomic Energy on August 13, 1955. Nuclear Energy Commission on June 22, 1957.
Chairman: Secretary of Health Paulino J. Garcia.
Vice-Chairman: Comdr. Marcelino E. Galinawan, Jr.
Committee Members: Dean C. A. Ortigas, Dr. Gregorio Y Zara, Col. Florencio A. Medina, Mr. Alfredo G. Eugenio, Consul Aurelio Ramos, Dr. S. Ador-Dionisio, Mr. Leopoldo G. Salazar, Mr. Pedro G. Afable.
Reactors:
Heterogeneous thermal two-position core pool-type research reactor being negotiated with assistance of U.S.A.E.C.

Poland

Pelnomocnik Rzadu do Spraw Wykorzystanca:
Energii Jadrowej, Polace Kulburg i Nauki, Warsaw.
Director: Prof. Soltan.
Reactors:
2 MW water-moderated, 10% enriched U235 reactor in course of construction. Supplied by U.S.S.R.

Portugal

Junta de Energia Nuclear:
Rua de S. Pedro de Alcantra 79, Lisbon.
President: Ing. José Frederico Ulrich.
Reactor:
1 MW pool type ordered from A.M.F.

Rumania

Institutul pentru Energia Nucleara al Academiei RPR:
Calea Victorie nr 125, Bucharest.
Director: Prof. Horia Hulubei.
Reactors:
2 MW research reactor to be supplied by U.S.S.R.

South Africa

Atomic Energy Board of South Africa:
Merino Buildings, Pretorius Street, Pretoria, Transvaal, South Africa.
Telephone: Pretoria 22540.
Cable Address: Isotope Pretoria.
Established: 1948.
Chairman: Dr. the Hon. A. J. R. van Rhijn, M.P.
Vice-Chairman: V. H. Osborn.
Secretary: J. A. Reid.
Commission Members: G. P. Jooste, Dr. S. M. Naude, W. G. Pyne, Mercier R. B. Hagart, C. S. McLean, Dr. D. H. Steyn, D. H. van Gend.
Departmental Head: Dr. A. J. A. Roux, research director.
Principal Organization: Council for Scientific and Industrial Research, P.O. Box 395, Pretoria.
Uranium Production:

1955	.. ..	3,290 tons
1956	.. ..	4,364 tons
1957	.. .. .. at the rate of	5,000 tons

Spain

Junta de Energia Nuclear:
Serrano, 121-Madrid.
Telephone: Madrid 34-54-04, 34-54-05, 53-54-03, 53-54-04, 53-54-05.
Established: October 22, 1951.
Chairman: Excmo. Sr. D. Eduardo Hernandez Vidal.
Vice-Chairman: Excmo. Sr. D. Jose Ma. Otero Navascues.
Director General: Excmo. Sr. D. Jose Ma. Otero Navascues.
Commission Members: Sr. D. Antonio Colino Lopez, Excmo. Sr. D. Armando Duran Miranda, Excmo. Sr. D. Manuel Lora Tamayo, Ilmo. Sr. D. Jose Romero Ortiz de Villaciain.
Departmental Heads: D. Demetrio Santana Perez (Division de Iny. y Explo. Minera), D. Carlos Sanchez del Rio (Division de Fisica), D. Ricardo Fdez. Cellini (Division de Quimica), Sr. D. Luis Gutierrez Jodra (Division de Materiales), D. Francisco Pascual Martinez (Secretario Tecnico), D. Diego Galvez Armengau (Secretario General).
Principal Organizations: TECNATOM, Barquillo, No. 1. Babcock and Wilcox Espanola, Paseo de la Castella, 44. Centrales Nucleares del Norte.
Reactors:
3 MW swimming pool research reactor being built by General Electric (U.S.A.). Due for commissioning in March, 1958.

Sweden

Atomkommittén:
Ranhammarsvägen 22, Bromma, Sweden.
Telephone: 26 90 80.
Established: December, 1945.
Chairman: Governor Malte F. Jacobsson.
Secretary General: Fil. Dr. Gösta W. Funke.
Commission Members: Prof. Hannes O. G. Alfvén, Prof. Torsten V. Gustafson, Prof. Bo M. S. Kalling, Managing Director K. Ragnar Liljeblad, Head of a Department Torsten K. A. Magnusson, Prof. C. Edmund B. Schjanberg, Col. Torsten A. Schmidt, Prof. K. Manne G. Siegbahn, Prof. P. Otto Stelling, Director-General Hakan K. A. Sterky, Prof. The Svedberg, Prof. Ivar Waller.
Principal Organizations: Aktiebolaget Atomenergi, P.O. Box 9042, Stockholm 9, Sweden. ASEA Electric, Västeras (in association with Atomics International, U.S.A.), Atomkraftkonsortiet, Krangende AB et Co., Stockholm.
Reactors:
R 1, 600 kW natural uranium, heavy-water research reactor at Stockholm. Went critical in 1954.
R 2, 30 MW (thermal) high flux materials testing reactor at Studsvik Research Centre, scheduled for completion next year. Ordered from A.C.F.
R 3, 98 MW (thermal), 15 MW (electric) uranium oxide, heavy-water district heating reactor. Scheduled for operation in 1960.
Parallel with R 3 there is a similar district heating reactor project, "Adam," at Västeras.
A 75-100 MW nuclear power station, "Eve," is planned for operation before 1965.

Switzerland

Schweizerische Studienkommission für Atomenergie:
Hallwylstrasse 4, Bern.
Telephone: Bern 617723.
Established: 1945.
President: Prof. Dr. P. Scherrer.
Secretary: Dr. A. Krethlow.
Federal Government Delegate: Dr. h.c. O. Zipfel.
Principal Organizations: Reaktor A.G., Berngasse 29, Zürich; Communauté d'Intérêts pour l'Etude de la Production et de l'Utilisation Industrielle de l'Energie Nucléaire, 10, Avenue de la Gare, Lausanne; Atomkraft A.G., Brown Boveri and Co. A.G., Baden; Atomelektra A.G., Elektrowatt A.G., Talacker 16, Zürich; Suisatom A.G., Bahnhofplatz 3, Zürich; Société Nucléaire S.A., 10, Avenue de la Gare, Lausanne.
Reactors:
1 MW swimming pool research reactor in operation at Wurenlingen for Reaktor A.G.
10 MW natural uranium heavy water reactor in course of construction for Reaktor A.G.

Thailand

Ministry of Communications:
Bangkok, Thailand.
Minister: Air Marshal Muri Mahasantana Wechayant Rangsarit.

Turkey

Erkaniharbiyiye Umunmiye Riyaseti:
ABC Dairesi Baskanligina, Ankara, Turkey.
Director: Prof. Besim Tanyel.
Reactors:
Istanbul University hopes to obtain a research reactor from the U.S.

United Kingdom

U.K. Atomic Energy Authority:
St. Giles Court, London, W.C.2.
Telephone: Museum 6838.
Telegrams: Depaten, Westcent, London.
Established: August 1, 1954.
Chairman: Sir Edwin Plowden, K.C.B., K.B.E.
Members: Sir John Cockcroft, O.M., K.C.B., C.B.E., F.R.S. (Scientific Research); Sir Leonard Owen, C.B.E. (Engineering and Production); Sir Wm. Penney, K.B.E., F.R.S. (Weapon Research and Development); Sir Donald Perrott, K.B.E. (Finance and Administration); W. Strath, C.B. (External Relations and Commercial Policy).
Part-time Members: Lord Citrine, Sir Ivan Stedeford, K.B.E., Sir Rowland Smith, C. F. Kearton, O.B.E.
Secretary: D. E. H. Peirson.
Principal Organizations: A.E.I.—John Thompson Nuclear Energy Co. Ltd., Crown House, Aldwych, London, W.C.2; Atomic Power Constructions, Ltd., 28-30 Theobalds Road, London, W.C.1; English Electric—Babcock and Wilcox—Taylor Woodrow, Marconi House, Aldwych, London, W.C.2; G.E.C. Simon-Carves Atomic Energy Group, Erith, Kent; Hawker-Siddeley—John Brown Nuclear Construction Ltd., The Sanctuary, Westminster, London, S.W.1; Hawker-Siddeley Nuclear Power Co. Ltd., Langley, Slough, Bucks; Head Wrightson Processes Ltd., 24-26 Baltic Street, London, E.C.1; Humphreys and Glasgow Ltd., 22 Carlisle Place, London, S.W.1; Mitchell Engineering Ltd., 1 Bedford Square, London, W.C.1; Nuclear Power Plant Co. Ltd., Booths Hall, Knutsford, Cheshire; Ruston-Kier Nuclear Power Plant, Lincoln; Vickers Nuclear Engineering Ltd., Broadway House, Westminster, London, S.W.1.
Reactors:
A.E.R.E., Harwell:
100 kW GLEEP, graphite-moderated, research, critical, 1947.
6.5 MW BEPO graphite-moderated, research, critical, July, 1948.
ZEPHYR, Pu, fast, research, zero-energy, critical, 1954.
DIMPLE, heavy water, lattice experiments, zero-energy, critical, 1954.
NERO, U, Pu, graphite, research, zero-energy, critical, 1957.
LIDO, S.P., shielding experiments, 100 kW, critical, September, 1956.
NEPTUNE, H_2O, naval research, zero-energy, critical, November, 1957.
DIDO, D_2O, materials irradiation, 10 MW, December, 1957.
PLUTO, D_2O, materials testing, 10 MW, criticality expected April, 1958.
Cumberland:
Windscale (2) graphite-moderated, Pu production, critical, 1950-51 (not now in operation).
Calder A (2) graphite-moderated, Pu and electricity production, 180 MW; 46 MW (E) per reactor, May, 1956; January, 1957.
Calder B (2) similar to A. Estimated criticality, June, 1958; January, 1959.
Chapelcross:
Chapelcross (4) similar to Calder A and B. Estimated criticality, January, 1959; May, 1959; September, 1959; January, 1960.
Dounreay:
Fast experiment reactor, 60 MW. Estimated criticality, April, 1958.
DMTR, heavy water, materials testing, 10 MW. Estimated criticality, April, 1958.
ZETR, tank, criticality experiments, zero-energy, critical, August, 1957.
A.W.R.E., Aldermaston:
5 MW Merlin. Estimated criticality, 1958.
Civil power programme:
Berkeley (2) graphite-moderated, 140 MW (E) per reactor. Estimated criticality, 1960-61.
Bradwell (2) graphite-moderated, 150 MW (E) per reactor. Estimated criticality 1960.
Hunterston (2) graphite-moderated, 150 MW (E) per reactor. Estimated criticality, 1961-62.
Hinkley Point (2) graphite-moderated, 250 MW (E) per reactor. Estimated criticality, 1962.
Civil research:
A.E.I. Merlin, research, 5 MW. Estimated criticality, April, 1958.

U.S.A.

U.S. Atomic Energy Commission:
19th Street and Constitution Avenue, Washington, D.C.
Telephone: ST 3-8000.
Established: December 31, 1946.
Chairman: Lewis L. Strauss.
Commissioners: Dr. Willard F. Libby, John F. Floberg, John S. Graham, Harold S. Vance.
Principal Organizations: Los Alamos Scientific Laboratory, Los Alamos, New Mexico; Argonne National Laboratory, Lemont, Illinois; Oak Ridge National Laboratory, Oak Ridge, Tennessee; Brookhaven National Laboratory, Upton, Long Island, New York; Radiation Laboratory, Livermore and Berkeley, California; Bettis Plant, Pittsburgh, Pennsylvania; Knolls Atomic Power Laboratory, Schenectady, New York.
Principal Manufacturers: Allis-Chalmers Manufacturing Co; ACF Industries, Inc.; Aerojet-General Corp.; Alco Products, Inc.; AMF Atomics, Inc., a subsidiary of American Machine and Foundry Co.; American Radiator and Standard Sanitary Corp.; Babcock and Wilcox Co., Bendix Aviation Corp.; Combustion Engineering, Inc.; Consolidated Vultee Aircraft Corp.; Daystrom, Inc.; E. I. DuPont de Nemours and Co.; Foster Wheeler Corp.; General Atomic Division of General Dynamics Corp.; General Electric Co.; General Nuclear Engineering Co.; H. K. Ferguson Co.; Isotope Products, Inc.; Kaiser Engineers, Division of Henry J. Kaiser Co.; Lockheed Aircraft Corp.; Martin Co.; Atomics International, a Division of North American Aviation, Inc.; National Advisory Committee for Aeronautics; Nuclear Development Corp. of America; Pratt and Whitney Aircraft Division, United Aircraft Corp.; Union Carbide Corp.; Westinghouse Electric Corp.
Reactors:
U.S. reactors were last listed in *Nuclear Engineering*, October, 1957, page 467. Reactors commissioned in 1957 include:
EBWR—experimental boiling water reactor—of 5 MW(E) at Argonne National Laboratory. Dedicated, February 9.
SRE—6.5 MW(E) sodium reactor experiment—at Santa Susana, California. Critical in April.
APPR—army package power reactor—achieved criticality at Fort Belvoir, Va.
OMRE—organic-moderated reactor experiment—became critical on September 17.
HRE2—homogeneous reactor experiment.
PWR—60 MW(E) pressurized water reactor at Shippingport, Pa.—went critical on December 2.
5 MW Vallecitor boiling water reactor went critical in November.
EBR-1 re-commissioned.
ETR—175 MW engineering test reactor—went critical October 20.
1 MW pool-type supplied to Michigan University by Babcock and Wilcox and similar reactor at Livermore (Foster Wheeler Corp.).
Propulsion: Some 17 nuclear-powered submarines are planned or in course of construction. Two completed in 1957 are the "Sea Wolf" and the "Skate." Projects for naval and merchant surface ship propulsion. Aircraft: Reactors being developed for this class of propulsion.

U.S.S.R.

Central Board for the Use of Atomic Energy:
Moscow, U.S.S.R.
Established: 1956.
Director: Yefim Pavlovich Slavsky.
Assistant Director: N. A. Nikolayev.
Reactors:
5 MW experimental power reactor at Moscow. Went critical June, 1954.
Projects for three types of power reactor under the present five-year plan: (1) graphite moderated, steam and water cooled; (2) pressurized water moderated and cooled (POWR); (3) heavy water moderated and CO_2 cooled, natural uranium units.
Experimental low capacity reactors include a 70 MW boiling water unit with single circuit arrangement; a 50 MW sodium-cooled graphite-moderated unit; a homogeneous reactor and fast breeder.
Propulsion: Reactor for the Soviet icebreaker "Lenin."

Venezuela

Instituto Nacionale des Neurologia, Neuropsiquiatria et Investigaciones Cerebrales:
c/o Ministra de Sanidad, Avenida Bolivia, Caracas.
Director: Dr. H. Fernández-Morán V.
Reactors:
3 MW swimming pool reactor for Venezuelan Research Centre. Ordered from General Electric (U.S.A.).
Two 12.5 MW boiling water reactors also believed to be on order from General Electric (U.S.A.).

Yugoslavia

Federal Nuclear Energy Commission:
Nemanjina 6/1, Belgrade, Yugoslavia.
Telephone: Belgrade 29-161.
Established: March 19, 1955.
President: Aleksandar Rankovic, Vice-President of Federal Executive Council.
Vice-Presidents: Svetozar Vukmanovic, Vice-President of Federal Executive Council; Professor Pavle Savic, academician, President of the Scientific Council of the Institute for Nuclear Sciences "Boris Kidric."
Governing Committee: Ivan Gosnjak, Secretary of State for National Defence; Milentije Popovic, President of the Committee for National Economy of Federal Executive Council; Veljko Zekovic, Secretary of Federal Executive Council; Slobodan Nakicenovic, Secretary of Federal Nuclear Energy Commission; Miladin Radulovic, Director of Bureau for Nuclear Raw Materials.
Commission Members: Ing. Ljubomir Barbaric, Department Head of Federal Nuclear Energy Commission; Ing. Bela Bunji, Director of Institute of Technology of Mineral Raw Materials; Rade Bulat, Major-General, Yugoslav National Army; Ing. Milos Bucar, Department Head of Federal Nuclear Energy Commission; Dr. Ing. Toma Bosanac, Chief of Projects Bureau of the "Rade Koncar" factory; Ing. Bozidar Gustin, Director of the "Litostroj" factory, Ljubljana; Dr. Drago Grdenic, Professor of the Zagreb University and member of the Scientific Council of "Rudjer Boskovic" Institute; Dr. Franc Kos, Authorized Minister of the Secretariat for Foreign Affairs; Dr. Herbert Kraus, Secretary for National Health of Federal Executive Council; Dr. Anton Moljk, Docent of the Ljubljana University and member of the Scientific Council of the "Jozef Stefan" Institue; Vojko Pavicic, Director of Institute for Nuclear Sciences "Boris Kidric"; Anton Peterlin, President of the Scientific Council of the "Jozef Stefan" Institute, Ljubljana; Dr. Stojan Pavlovic, academician, University Professor, member of the Council of Experts of Federal Geological Survey; Ing. Milorad Piper, Director of Institute for Production and Enrichment of Plants, Zemun-Polje; Ing. Milorad Ristic, member of the Administration Board of Institute for Nuclear Sciences "Boris Kidric"; Dr. Ivan Supek, University Professor and President of the Scientific Council of the "Rudjer Boskovic" Institute; Ing. Salom Sulca, Department Head of Federal Nuclear Energy Commission.
Principal Organizations: The Bureau for Nuclear Raw Materials, Nemanjina 6/1, Belgrade. Tel. 29-704. The Institute for Nuclear Sciences "Boris Kidric," Vinca, Belgrade. Tel. 41-227, 41-425. The "Rudjer Boskovic" Institute, Bijenicka cesta 56, Zagreb. Tel. 38-541. The "Jozef Stefan" Institute, Jamova cesta 55, Ljubljana. Tel. 22-118.
Reactors:
The first Yugoslav research reactor is being constructed at The Institute for Nuclear Sciences "Boris Kidric."

TECHNOLOGICAL REVIEW

An Appraisal of Current Trends

PROBABLY the most important single technological achievement in the U.K. over the past year has been the continued satisfactory operation of the first reactor at Calder Hall, in addition to which should be observed the start-up of reactor No. 2 and the steady progress made on Calder B and the Chapelcross installations. No. 1 reactor diverged on May 22, 1956, steamed some three months later and fed electricity into the grid system for the first time when the Queen officially opened the station on October 17, 1956. A short time afterwards the reactor was shut down for examination and modifications were made to the fuel elements to counteract the bowing which developed as the result of creep. The simple restraint system that was incorporated proved entirely successful and has resulted in a certain amount of re-thinking on the advantages of individual stacking of fuel elements. Although the majority of the design consortia prefer individually supported elements and simple stacking has many opponents, the additional complexity involved is a disadvantage and there is by no means a unanimity of opinion on the relative merits. One result of the creep problem has been an influence on the design of fuel elements heat transfer surfaces. Considerable research has gone on into the optimum fin shapes for high heat transfer coefficient, small pressure drop and good mechanical properties; this has led to a progressive tendency towards a longitudinal fin as opposed to a transverse.

With the limitations imposed by magnesium as a canning material, the necessity for a cylindrical element to conserve reactivity and the maximum temperature limitation imposed by the alpha/beta phase change in uranium any marked up-grading of fuel channel rating in the Mk. II designs is ruled out. (In this terminology Calder is regarded as the prototype, the first run of tenders as Mk. I and the second run as Mk. II. Hinkley Point must be considered as more nearly a Mk. II design than a Mk. I.) The increased overall rating of the Hinkley Point reactor is largely brought about by a greater utilization of the reactor vessel volume and a consequent big improvement in flux flattening. Still greater improvements are envisaged and it is likely that some reduction in overall reactivity will be tolerated to increase further the volume utilization.

Pressure Vessels

1957 has seen the changeover in reactor construction from 2-in. plate at Calder Hall to 3-in. plate at Bradwell and Berkeley. The site welding of the bigger plate has required an improvement in welding techniques and has stimulated the development of new electrodes. This changeover to 3-in. has not been accomplished without some difficulties but it can be considered that this thickness can be tackled with confidence and already in France for EDF1 a 4-in.-thick pressure vessel is contemplated.

In three out of four cases, the Mk. I designs saw the break-away from the cylindrical shape to the spherical shape of pressure vessel but all designs employed a plain continuous surface and can be regarded as essentially conventional. In the relatively near future we are likely now to see changes in this simple design and a breaking-away from established practice. At the same time results should start to come in on the concrete pressure vessels of G1 and G2. It is unlikely, however encouraging these results are, that there will be any immediate reaction but it is possible that when very large stations are considered (say 500 MW per reactor) this approach might be reconsidered in this country.

In France no doubt experience will be wanted on EDF1 operation or at least construction before any firm decisions are made on EDF3 and 4.

A subject concerning pressure vessels that came in for some discussion during 1957 was the proper method of support and the two schools of thought (skirt and frames) are both strongly supported. The theoretical examination of this problem will continue over the next few years but the ultimate decision cannot be taken until some operational experience has been obtained.

Research into the production of better steels is continuing, chiefly in the direction of higher stress, methods of insulation and cooling being devised to ensure that the steel does not enter the creep region. Nevertheless, the advantages of a better creep-resistant steel are clear but a long proving period is necessary before any significant departures from well-tried formulae can be contemplated.

Fuel Elements and Components

The fundamental changes in the design which would materially affect the rating of the gas-cooled graphite-moderated reactor, such as the introduction of plate-type fuel and beryllium canning, have received active consideration and a very comprehensive programme of research on beryllium in both industry and the Authority is getting under way. Certainly the later Mk. II designs will not include beryllium and there is every reason to suppose that these developments must be considered as long term.

Apart from the significant improvement in volume utilization mentioned above, changes in reactor design are likely to show only marginal advances but the detailed effort now being expended on the cheapening and improving of component designs should yield results. Final designs are not yet complete for some of the components of the Mk. I reactors and Mk. II designs will certainly include more elegant units such as B.S.D. gear and shaft seals. At the same time components which 12 months ago were in short supply, or for which only rough specifications could be given, are now becoming commercially available. The manufacturing potential for example of bellows for expansion units is increasing rapidly and the supply of glandless valves in terms of variety, cost and delivery times is improving.

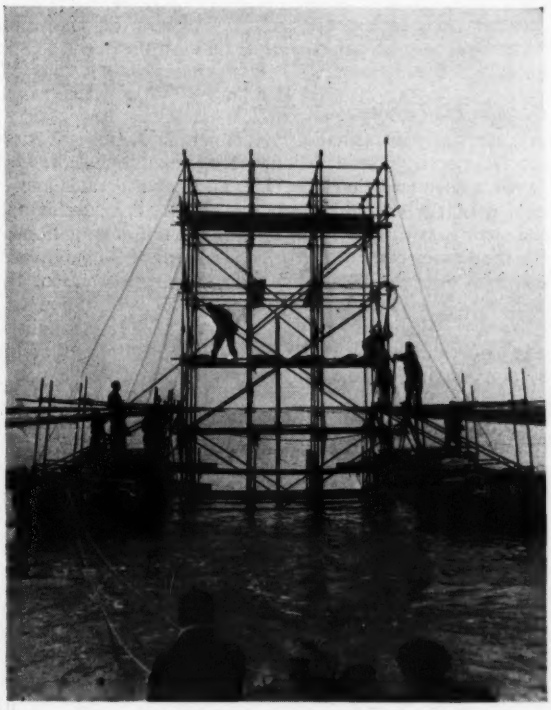
Towards the end of 1958, the Anglo-Great Lakes factory near Newcastle should start production of graphite which will mean that two sources are available in the U.K. At the same time a number of companies which have been setting up machining facilities will be in continuous production and the graphite situation by the middle of 1959 should be reasonably comfortable.

U.K. Programme

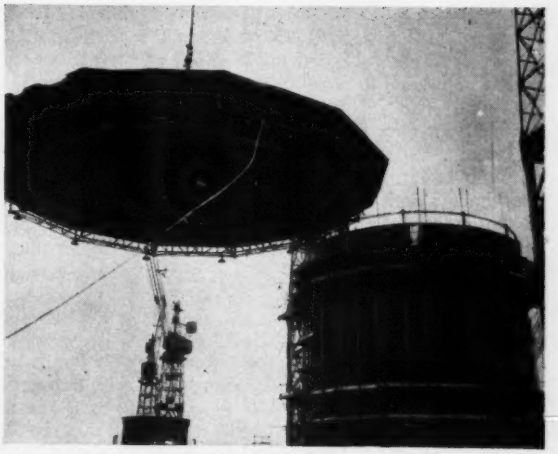
1957 has been in some respects the most significant year so far in peaceful nuclear energy developments as it has seen the start made in the United Kingdom of four commercial nuclear power stations, which will herald the beginning of the nuclear generation age. The programme which at the beginning of the year stood at a mere 2,000 MW by 1965 was increased to 6,000 MW and many felt

that even this was a pessimistic figure. Financial considerations caused an extension of the period and therefore a slight slowing down of the programme, but it is unlikely that this trend will be extended and when the Mk. II and Mk. III designs are fully appreciated it is possible that the 6,000 MW might yet be met in the 1965-66 year. It must be remembered also that the next run of tenders will see the fifth consortium entering the field, a consortium which has been strengthened during 1957 by the addition of Fairey's and Elliott's.

The reorganization of the C.E.A. will begin to take effect during 1958 and the influence of Sir Christopher Hinton as chairman of the C.E.G.B. will no doubt be felt. His changeover from the A.E.A. has inevitably altered the balance of relations between these two organizations and between the board and industry. We can expect that the long-term policies of the C.E.G.B. will be more consistent than those of the C.E.A. and that the proper place of nuclear energy in relation to oil and small coal will be defined.



(Above) The EL3 testing reactor under construction at Saclay. (Below) Drilling tower being towed into position for the Hinkley Point nuclear station under construction by the English Electric/Babcock/Taylor Woodrow group.



Lifting the roof protecting pressure vessel construction at the Berkeley power station of the John Thompson/Simon-Carves group.

The experimental organic moderated reactor at Harwell utilizing Dowtherm.

Over the past year, alternative systems of power generation have received active consideration and the superiority of the gas-cooled, graphite-moderated reactor over all other types has been manifested—the technology of alternative systems being in most cases far more complex than originally anticipated. From the point of view of overall philosophy, the most significant factor that has received world wide attention has been the ever-increasing amount of the known uranium reserves, and the steady improvements that have been made in the extraction techniques. The mining and refining of natural uranium has now reached a point when suppliers are anxious about the probable demand rather than the reverse. The net result is that the required characteristics of a reactor with a positive gain

factor have changed and the economics of fuel cycling have assumed a prime place in overall cost calculations. This has however strengthened the position of the Calder-type reactor, but what to do with the plutonium is still a burning question. The very generous prices offered by the U.S. during 1957 are a further incentive to produce and extract plutonium, but the place of this metal in the overall programme is far from clear. It is to be hoped that the experiments both regarding the physics and the metallurgy of the metal will be intensified and that during 1958 some real answers can be produced on whether plutonium can be burnt in a Calder-type or whether it is necessary to move to a more exotic system.

Pressurized Water Systems

There are indications that plutonium might be burnt in pressurized water systems which would make the large-scale developments in the U.S. in 1957 of even greater significance. In America, 1957 saw the start-up of Shippingport and the successful operation of both EBWR and APPR. It is too early yet to assess these reactors technologically but we can expect 1958 to advance the knowledge on the operation of these systems to a very considerable degree. The cost problem however has still to be solved and perhaps of even more significance in the U.S.A. was what has been called the agonizing cost reappraisal that went on in the later summer and the realization by industry that nuclear power was not cheap. Where economics are not a consideration, the pressurized water reactor can be considered to have proved itself a reliable and versatile system of power generation. The success of Rickover's submarine programme as evidenced by the Nautilus must be considered resounding and it is to be hoped that modifications to the McMahon Act will allow the fullest U.K. access to the information on design and operation.

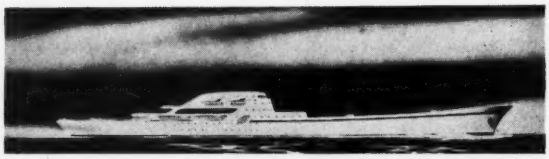
Sodium Cooling

The decision to abandon the further development of the Sea Wolf propulsion system shows that the U.S.N. does not regard Na cooling as an immediate proposition.

Nevertheless, SRE is now in operation and experience built up over the next few months should allow a final assessment of the sodium/graphite system to be made. There are indications that the graphite sealing problems are not insuperable and that the zirconium cladding adopted for SRE is not the only approach, but even supposing this aspect of the technology can be confidently solved there is little incentive, certainly in the U.K., for the system to receive commercial development.

H.T.G.C.

At the beginning of 1957, the system which was believed to hold out the greatest promise was the high temperature gas-cooled reactor which, it was felt, could be engineered in a single jump. Opinions have changed progressively as the problems involved have become appreciated and it is now believed that the H.T.G.C., although still holding promise, must now be considered as the logical ultimate development of the Calder type. A reactor experiment has just started construction at Winfrith, but this is a long-term project. One of the major difficulties is to choose between the development of an impervious element or design for an active circuit. The metallurgists have not yet seen their way to develop the required elements whilst the engineering problems raised by the second approach are formidable. A break-through in this field cannot be expected and a progressive up-rating of Calder with a reduction in size is the most likely line of approach towards a reactor capable of driving a gas turbine.



Artist's impression of the U.S. nuclear-propelled merchant ship.

Fast Reactor

Although it can no longer be regarded as a prototype, and the relative importance of the system has altered, the Dounreay Fast Reactor will at least be filled with sodium this year and may go critical. A greater appreciation of the control difficulties, quite apart from the influence of the Fleck Committees, will probably reduce the speed at which the reactor is run up to power. The experiment will nevertheless provide a great deal of information on the technology of sodium circuits but this must again be considered as a very long-term project particularly when it is remembered that even the original programme did not anticipate the installation of a plutonium core before 1963. In America progress is unlikely to be more rapid.

HAR and LMFR

In the course of its career the HAR has been through many phases but only relatively recently has the full import of the corrosion problem been understood. Research both in this country and in the U.S.A. has continued on the system but 1957 saw no fundamental step forward. This system will probably be the first to be affected by any cuts in research effort and its European future is likely to lie with O.E.E.C., possibly at Winfrith Heath.

Similarly, LMFR has passed through a number of periods of depression and optimism. LMFRE in America is still being designed and there seems little doubt that the reactor can be built. However, the life of the container is another matter and the reprocessing system is not even established yet in principle. The system must be regarded as a very long-term project and research in this field must be treated only as a means of evaluating the general technology of liquid fuels.

Organic Moderation

Particularly for small reactors, organic moderation is receiving active consideration. It is probable that the U.S. is more advanced than the U.K. and has a greater appreciation of the effects of radiation on organic liquids and the steps that can be taken to mitigate the degradation of the moderator-coolant. Work in the United Kingdom will continue during 1958 in this field and by the end of the year it is possible that the accumulated information will allow a realistic evaluation to be made of the potentialities of the organic-moderated system. The attractions of the system are undeniable but a more concentrated effort is required to determine its real practical value. It may well be that further study will bring to light the necessity for developing new technologies such as has happened with the two previous reactors discussed. At present, indications are that the damage to the organic can be accommodated and a reactor can be made to work with reasonable economics.

Heavy Water

Both in the U.K. and in the U.S.A. heavy water has received only a small amount of attention as a moderator-coolant for power systems, but we can look in 1958 for a turning towards heavy water and for particular attention to

be paid towards the gas-cooled, heavy water-moderated type. The developments in both Sweden and Canada will be followed with considerable interest and the end of the year could see the system being actively considered for ship propulsion.

Ship Project

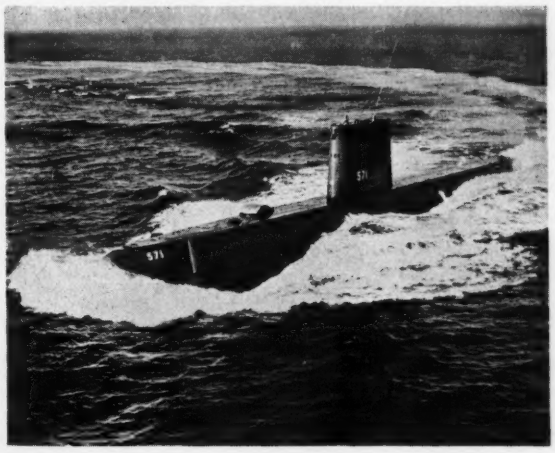
There will be keen interest in the U.K. when a nuclear-propelled merchant ship project is started. A report was given at the end of the year on the studies carried out at Risley on the application of a gas-cooled graphite-moderated reactor to a large ship and showed that the project was not particularly encouraging. There is no a priori reason why any fission system can economically propel a ship, but, although the U.K.A.E.A. can be expected to resist any premature entry into this field, pressure from shipping circles may convince it that a land-based project aimed ultimately at the ship should be started. At this juncture it would seem that a reasonable compromise is to examine the merits of the organic-moderated system and the heavy-water-moderated gas-cooled system, select one of these for more intensive development and then build a land-based experiment to prove it. There is considerable world-wide interest in ship propulsion as evidenced by the American cargo passenger ship which it is not pretended will necessarily provide an economic solution. At the same time, Japan, Germany, France, Sweden and Norway are all reported to be actively engaged on the designs of a merchant ship.

The Russian ice-breaker "Lenin" recently launched is a different proposition. The specialized nature of this vessel makes it ideal for a reactor experiment and economics are no doubt of secondary importance. Any information that the U.S.S.R. releases on this project in the next 12 months will be received with considerable interest by designers all over the world. Similarly the vast American submarine programme is in a different category and the present policy of building one of each of the major surface naval vessels with pressurized water propulsion units is a vast nuclear project but not related to costs.

Testing Reactors

1957 saw the commissioning of a number of important materials irradiation reactors: DIDO in the U.K., EL3 in France, ETR in the U.S.A. and NRU in Canada. These, together with reactors already commissioned or under construction, will considerably increase experimental facilities throughout the world and will allow the more rapid advancement of irradiation technology. This should have a significant influence on metallurgical developments but the results of these experiments must be considered as on a long-term basis and no immediate influence should be expected on reactor technology. The cost of installing loops in these reactors has received more attention over the past months and the desire for an extended programme of test-reactor building has been modified.

The U.S.N. "Nautilus"



Inserting a fuel element in the S.R.E.

The installation and the contracting for small research reactors in many countries throughout the world should lead in a few years' time to a considerable increase in the overall experience in the atomic energy field. The influence that this can have on future policies has yet to be seen and some years must elapse before reactors for power have any significance outside the industrialized countries.

Fusion

The thermo-nuclear reaction as a source of controlled power has at regular intervals sprung into the headlines and although 1957 may be considered as a milestone in progress along this route it would be misleading to suppose that any major break-through has taken place. We shall be giving in greater detail the apparatus that has been developed in the U.K. and the progress that has been made with it in the March issue of *Nuclear Engineering* but the general state of the technology can be provisionally summarized as equivalent to the state of fission technology in, say, 1939. The U.S.A. and the U.K. have been working in the fullest co-operation and ZETA at Harwell is probably the first apparatus outside Russia (from whom there has been little information since the Kurchatov lectures at Harwell) to produce neutrons which are probably of thermo-nuclear origin. It would be wrong to take the analogy to the fission programme too far, as one of the major stumbling blocks with fission development is the generation of fission products implicit in the reaction and these are not present in the fusion reaction. All the same it is unlikely that investment on the scale of 1939-45 will be possible. We have still to see a positive energy gain in the reaction and although the theoretician can predict that this is feasible, the practical problems of constructing machinery which can be compressed into the volume available, which will withstand the temperatures and reactor conditions that will be encountered, have yet to be tackled in a practical manner. On general philosophical grounds we may perhaps deduce that a positive energy gain will be achieved, but this is still a long way from proving that it can be achieved economically.

Technical Literature of 1957

A classified guide for rapid reference to the principal articles of the year

RESEARCH REACTORS

A simplified study has been made by Osredkar and Stephenson(1) of the inside-reflected thermal and fast reactors for the purpose of finding the best solution for a low-power high-thermal flux experimental reactor.

Aerojet-General Nucleonics have designed a compact low-cost research reactor, the AGN-201, where high thermal neutron flux is not necessary but low cost, maximum safety and high sensitivity are required(2).

The Argonne National Laboratory has released details of the Argonaut reactor, a 10 kW thermal water-moderated graphite reactor. The total fissionable material will be about 4 kg U235. Lennox and Kelber(3) describe the installation, which is a facility for nuclear engineering training and research. Armstrong and others(4) cover the engineering and constructional features, including cost summaries. The cost will be less than $100,000. From the physics viewpoint, Kelber(5) presents three different methods of solving the two-group equation for the critical loading of Argonaut for different types of core configurations.

Belgium's BR-1 reactor at Mol is a natural U, graphite, air-cooled reactor with a maximum neutron flux exceeding 10^{12} n/cm²-sec. Stiennon(6) gives details of the reactor structure, control and characteristics. Design and constructional features of BR-2, the Belgian material and engineering test reactor, are described by Planquart (7).

The Engineering Test Reactor, which was built by Phillips Petroleum at Idaho Falls under contract to A.E.C., became critical during September, 1957. De Boisblanc and others(8) give details of the full-scale mock-up of the core and reflector to facilitate reactor physics and engineering measurements. The design and construction of the reactor, the building of the reactor core, engineering facilities and a discussion on test reactors is covered by *Nucleonics*(9) and by Bush and others(10). Elgert and others carried out a study(11) on an advanced engineering test reactor for the purpose of testing water, gas and liquid metal-cooled fuel assemblies, and propose a system of seven separately cooled and controlled reactors grouped in a common shield.

Bray and Leyse(12) have made a preliminary design study of a food irradiation reactor that will process 3,000 lb/h at a dose of 2×10^6 rep. An MTR-type core is surrounded by a light water solution of indium sulphate.

Details have been published of the research reactors being operated by the U.K. Atomic Energy Authority. Fenning(13) gives brief descriptions of design, construction and operation, and the contributions that they are making to the development of the nuclear power programme. Details of the engineering aspects of DIDO and the control system have been covered by *Nuclear Engineering*(14). This enriched-uranium heavy water reactor has a flux of 10^{14} n/cm²-sec, which is the highest in Europe.

MERLIN is a medium flux research reactor designed for a maximum thermal power of 5 MW. Aspects covered by Chick and Salmon(15) include the control and instrumentation system, safety precautions for core adjustment and maintenance, fission product activity and effluent disposal.

A preliminary design study has been made by Link and others(16) at Argonne of a 250 MW heterogeneous research reactor, the "Mighty Mouse," for basic research neutron beam experiments and irradiation studies. The peak thermal neutron flux level will be 5×10^{15} n/cm²-sec.

Hurst(17) points out the usefulness of NRX in many types of research and discusses the operation and control of the reactor. Lieberman(18) is concerned with the design, fabrication and testing of the Zircaloy in-pile tube for the NRX control thimble.

NRU, with a nominal heat output of 200 MW, will probably be the most powerful neutron flux producer of its type in the world, according to Gilbert(19), who describes design and operation (see also *Nuclear Engineering*, Jan., 1958). McKay(20) using an equivalent one-group homogeneous model, has studied the reactivity effects in NRU of U235 burn-up, the production and burn-up of Pu239 and the production, burn-up and decay of Xe135 and Sm149. He has also calculated the output and reactivity load of the loops in the reactor(21).

The proposed O.R.N.L. research reactor ORR has been designed to deliver an average thermal neutron flux of 1.3×10^{14} n/cm²-sec. at initial power level of 20 MW. Beryllium reflector pieces, cooling and moderation by the forced circulation of demineralized water and the use of MTR fuel elements, are among the details described by Cole and Gill(22) of this pool-type reactor. A report has been made on operational features of X-10, a graphite moderated, air-cooled natural uranium reactor, and of LITR, a water-cooled and moderated, enriched uranium reactor(23).

Design details, the operation and purpose of the West German research reactors have been revealed by Schopper and others(24). The Frankfurt reactor is a homogeneous water-boiler uranyl sulphate type, whilst those at Munich and Hamburg are swimming-pool types of 1 MW and 5 MW respectively.

India has installed its first swimming-pool type reactor. Titterton(25) indicates the importance of the 1 MW Trombay reactor against the broader background of India's nuclear energy development.

The Westinghouse Testing Reactor, Jones(26), is intended to help the design of nuclear power plant and will provide data on the changes in some structural materials that are likely to be produced by nuclear radiation.

FAST REACTORS

Fitting a fast breeder power reactor into a power reactor economy introduces many problems, including the ability to operate at high core-power density, difficulties in sodium technology, and the large inventory and frequent reprocessing which affect fuel costs and reactor safety(28).

The breeding principle was proven on zero-energy reactors at Harwell, and the practical problems created by transferring this principle to a power reactor are to be investigated at Dounreay, which has been developed as a full-scale reactor. Design details are fully described and include the sphere, the core and coolant, the core vessel, primary heat exchangers and electrical equipment. Civil and chemical engineering aspects are reviewed, together with the facilities for metallurgical plant research (29-34).

Detailed study of the neutron physics of fast reactors has been made since 1954 using a small, low-power-fast reactor, ZEPHYR, which has a plutonium core surrounded by a natural uranium envelope. Shepherd(35) describes the research that has been carried out to determine breeding characteristics of the system. The use of this reactor in determining the effective capture cross-sections of most of the natural elements, together with a large number of enriched isotopes, is outlined by Rose(36), who uses simple perturbation theory to show how the fast neutron capture cross-sections are dependent upon nuclear number and shell structure.

The Enrico Fermi reactor, which is under construction at Monroe, Michigan, has been designed for an initial output of 300 MW (heat) with an ultimate power of 430 MW. The generating capacity will be 156 MW. Heat is transferred from the reactor to the steam plant by primary and secondary sodium coolant circuits. The primary circuit and intermediate heat exchanger are located within the containment vessel. Details are given of the reactor construction, control rods, pressure vessel, the fuel-charging system, shielding and siting(37, 38, 39).

A design and feasibility study has been made at Oak Ridge of an externally cooled fused salt fast breeder producing 700 MW of heat. The fuel is plutonium mixed with the chloride of sodium, magnesium and uranium(40).

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TRENDS IN NUCLEAR POWER

The International Atomic Energy Agency had its first general conference in Vienna in October, when the administrative machinery was set up. Among the purposes of the Agency is the acceleration and enlargement of the contribution of atomic energy to peace, health and prosperity throughout the world in conjunction with the United Nations(41).

The Euratom treaty signed in March established a European atomic energy commission to supply Belgium, France, Western Germany, Italy, Luxembourg and the Netherlands with nuclear fuel, to carry out stringent inspection and to frame international agreements. Etzel(42) outlines the problems created by future total energy requirements in Europe and the place of nuclear energy in meeting them. Armand, Etzel and Giordani(43) report on the amounts of nuclear energy which can be produced in the near future in the six Euratom countries and the means to be employed for this purpose. The target envisaged the construction of 15 million kW of nuclear plant by the end of 1967 in order to stabilize conventional fuel imports early in the 1960s.

The O.E.E.C. has been responsible for two information conferences on nuclear energy and management, the first in Paris and another in Amsterdam. The April conference(44) was intended for businessmen and industrialists, and covered reactor techniques, economic aspects, the industrial uses of radioisotopes, materials and equipment, and the development programmes of European countries in particular. Proposals have been put forward for the co-operative development of nuclear power stations in Europe(45).

A further European management course was held in Brussels in September. Papers were read on research reactors; power reactor systems, such as the PWR, Yankee, EBWR, SGR, HRT, etc.; Calder Hall and its successors; Marcoule reactors; safety operations; waste disposal and fuel reprocessing; economics of nuclear power and the various programmes of France, Netherlands and Sweden(46).

Development of Australian activities has been extremely rapid during the past three years. The report for the year 1955-1956(47) reveals considerable achievements, not only in the prospecting and mining of uranium and thorium but also in basic research and development of nuclear power.

Reasons are given for the decision by the French Government Planning Commission to promote nuclear energy production on a large scale. Brief details are given of the gas-cooled graphite moderated reactors which enter the first stage of the programme, the production of constructional material, the nature of the research programme, and the extent of international co-operation(48, 49). Yvon(50) lists the reactors in France which have been constructed, are in construction, or are projected, including ZOE and EL2, the high flux EL3, the middle flux MELUSINE and the swimming-pool TRITON, the low flux Aquilon, PROSERPINE and MINERVA, and the power reactors G1, G2, G3 and EDF1.

Nuclear progress in Germany has been reviewed and a survey is made of energy requirements in relation to nuclear power(51). Hildebrand presents production and planning data and emphasizes the economic necessity in view of future coal reserves. Capacity forecasts are given for five-yearly periods up to 1980 and then up to the year 2000(52). The terms of the agreement between the German Federal Republic and the United States concerning co-operation and the supply of power reactors are commented on by Costa(53).

An overall review of Italy's industrial nuclear programme has been made which includes the country's power needs, potential in Southern Italy, the training of personnel, the activities of the Edison Group, and the problem of nuclear waste disposal(54).

The 1956 activities of the Netherlands Reactor Centre have been reviewed(55). Details of the operation and construction of the Delft research reactor are presented by Kleijn. This is a "swimming-pool" type designed in America by the American Machine and Foundry Co. Inc.(56). Milatz examines the country's nuclear energy requirements and economic aspects(57).

Sweden's programme provides for six reactors for district heating purposes and two power stations, one of 100 MW for 1960, and one of 350 MW for 1963. Svenke(58) discusses Swedish productive capacity for thorium, graphite, heavy water and zirconium, and considers the fuel cycle, efficiency and cost of elements, and processing problems. Hargö reviews(59) government estimates of expenditure for 1957, the overall energy position and current reactor projects. The 5th annual report for 1955-1956 has been issued by the Dutch-Norwegian Joint Establishment for Nuclear Energy Research(60).

In Switzerland, a natural uranium heavy water-moderated reactor is under construction. Sontheim(61) describes the main features and, in discussing the test programme, makes a comparison with the "swimming-pool" type in relation to suitability for various demands.

A brief survey has been made of the peaceful uses of nuclear energy in Britain, the present organization, and the progress in research which has led up to the nuclear power programme(62). The progress made by the United Kingdom Atomic Energy Authority for the year 1956-57, its third year of operation, has been reported(63).

The half-yearly progress report, January to June, of the United States Atomic Energy Commission summarizes the progress that has been made in nuclear power plant design and development(64). The development of the peaceful uses of atomic energy in America and the background political history is reviewed by Allardice and Trapnell(65).

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46. Atomic Energy Course for Management. Brussels, Sept. 8–21 1957. Papers.
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58. Svenke, E. *Teckn. Tidskr.* (Stockholm), **87**, Jan. 1957, 1–6.
59. Hargö, B. *Nuclear Engng.*, **2**, July 1957, 271–4.
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62. Central Office of Information. "Nuclear Energy in Britain." H.M.S.O. 55 pp.
63. U.K.A.E.A. 3rd Annual Report, April 1 1956–March 31, 1957. H.M.S.O. 58 pp.
64. U.S.A.E.C. "Major Activities in Atomic Energy Programs," January–June 1957 Washington. 257 pp.
65. Allardice, C., and Trapnell, E. R. *Nucleonics* **15**, Sept. 1957, 84–8.

POWER REACTORS

The scientific prospects of achieving competitive power from fission and fusion processes are discussed by Lewis(66).

The advantages and disadvantages of existing and future power reactor plants, particularly from the economic viewpoint, were the subject of a number of papers read at the World Power Conference in Belgrade. Roddis(67) is concerned with the cost and technical problems of small nuclear power plants of less than 40 MW(E), stressing the unreliability of many of the estimates that are being made in various quarters. Arms(68) also considers the complexity of costing and plant selection due to the widely varying circumstances in undeveloped countries and the many different types of reactor, which are examined as to their suitability in given circumstances. Shoupp and Jones(69) examine the points to be considered by undeveloped areas when adopting a nuclear energy programme. After justifying the selection of the PWR type, two typical units are described with 11.5, 68 and 143 MW(E) ratings.

Cockcroft(70) describes the Calder Hall

type of nuclear power station and discusses future developments, including the power requirements of the Commonwealth and European countries. A brief summary is also given of current research on the fusion reaction.

Establishing the future cost of electricity from nuclear power stations with Calder Hall-type reactors was the aim of Hinton in his Axel Ax:son Johnson lecture in Stockholm(71). It is estimated that by 1990 the cost of electricity will have fallen from 0.66d/unit (1960) to 0.32d/unit, as compared with 0.60d and 0.84d, the corresponding figures for coal-fired stations. Hinton also examines the characteristics of other power reactors(72).

The power reactor position in America has been examined as to government attitude, economic trends, and technical problems(73).

Capital costs of nuclear power stations, 1960-1975, are estimated by Jukes(74) to have a downwards trend from £125-135/kW to £80-85/kW. Real costs of conventional fuels will probably increase, allowing nuclear energy to become competitive over an increasingly wider field during the next few decades. Oswald(75) evaluates the cost per kWh for steam and nuclear power. Using a natural uranium graphite-moderated reactor, capital cost per kWh is estimated at 0.4d (4.7 mills) based on a load factor of 80% assuming annual capital charges of 90% on capital cost and 4% interest of the fuel stock. Operating costs are expected to be the same as for conventional power stations, i.e. about 0.3d (3.5 mills) per kWh, making a total of 0.7 (8.2 mills) per kWh.

Herron and Puishes(76) compare the cost of nuclear and conventional generation, and examine the prospects of reducing the cost of various components of nuclear plant. The difficulty of selecting plant in different countries is emphasized, power economics being the affecting factor. Bachl(77) discusses the cost factors which govern the price per unit produced both by conventional and nuclear power stations. The classification of reactor types is on the basis of circuit coolant and the combinations of different reactors with the main thermal cycles, data being given for overall efficiencies of nuclear stations as a function of coolant outgoing and return temperature.

Cost estimates for suitable types of reactor in providing heat and steam for industrial use are made by Allen-Williams and Whitworth(77). Sunderland(79) considers the application of nuclear heat or radiation to physical or chemical processes, replacing or supplementing electricity. Costs of coal-fired and nuclear stations are compared, and the effects of load factor and cheap electricity on industry are examined. In a survey of fuel strategy—Hartshorn(80)—it is estimated that the investment required to provide Britain with coal, nuclear power and residual imported oil will be about £4,500 million over the next ten years.

Lewis(81) analyses cost relations for "power breeder" and natural uranium reactors. Although the breeder is likely to be essential in large-scale power generation, possibly 10^9-10^{10} kW continuous output, natural uranium reactors may contribute 10^8-10^9 kW power at no greater cost. This compares with the present Canadian total hydro-electric capacity of 10^7 kW.

The cost and amount of nuclear power required in U.S.A. is estimated by Davies and Roddis(82). Capital costs per kW are expected to range from $300-400, compared with coal-fired plants at about $115-180. By about 1965-7, plant may be expected to approach competitive level and, by 1980, will be competitive with the conventional plant anywhere in U.S.A.

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POWER REACTORS: GENERAL

The progress that has been made in the U.S.S.R. in nuclear power station development has been revealed by Kurchatov(83). For 1956-1960 five experimental units are planned. Two stations will have water-moderated and cooled thermal and epithermal 200 MW reactors with 70 MW turbines. Another will be graphite-moderated, steam and water cooled, of the type used at the first power plant at the Academy of Sciences. A further 200 MW type will be heavy water-moderated and gas cooled. Several pilot plants are scheduled for 1959-1960. Detailed consideration is given to the physical problems of water-moderated reactors. Grigoriants(84) comments on the operation of the nuclear power station of the U.S.S.R. Atomic Energy Authority, describing the events from start-up to nominal power. Degrees of burn-up with partial and complete recharge of fuel channels are compared, and the residual heat generation in the fuel channels is discussed. Chemical analysis was made of the water in the first cooling circuit and an account is given of health physics and radiation dosimetry.

The merits of slightly enriched versus natural uranium reactors are considered by five U.S. experts(85), who support the view that natural uranium can hold its own in the nuclear power race. Weisner and others discuss low-enrichment thermal reactors for the production of plutonium and useful power(86).

Morris, Nicholls and Fenning(87) examine the possibilities of using a fluidized bed as the core of a nuclear reactor. Promising features are favourable heat transfer and even temperature throughout the reactor. Costly fuel fabrication operations may be avoided, provided that mutually compatible fuel, coolant, materials of construction, and moderator can be devised. There may be difficulties in realizing safety from nuclear accidents and in avoiding toxic hazards, erosion and corrosion.

Colgate and Aamodt(88) have departed from current procedure by presenting a conceptual design study for converting fission energy directly into electricity by causing ionized U235 gas to interact with a magnetic field. If uranium metal is used as the gas, the reactor wall temperature must be about 3,500° K. The minimum dimensions of the cylinder visualized are 3 ft radius, 150 ft length.

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GRAPHITE MODERATED, GAS COOLED

The development of gas-cooled reactors for power production has been traced by Moore(89). A popular account of Calder is given by Jay(90), who describes the design development and the nature of the engineering problems resolved. Many of the specialists who took part in the design and construction of Calder Hall revealed details hitherto unpublished, at a two-day symposium in November, 1956(91). Nineteen papers cover all the important features of planning, design and construction. Hinton introduces the series primarily with the purpose of putting the graphite-moderated gas-cooled reactor into its correct perspective in the nuclear energy field. Among the subjects discussed were: heat transfer experiments, the design and construction of the fuel elements, shield design, the basic reactor design, metallurgical problems and developments, the pressure vessel, uranium fuel handling, steam-cycle analysis, control equipment and instrumentation, the detection of faulty fuel elements, system control and protection.

The success of Calder Hall and the release of design information about Britain's nuclear power stations resulted in some hard thinking in America. Puishes, Herron and others(92) compare the economic and technical characteristics of Calder Hall and the P.W.R. The most important factors of each are examined to show their influence on the power-generating costs, first for the U.S.A. and then for construction in Great Britain. When built in America the power costs for the two reactors will be the same. In Britain, however, the Calder Hall design has a definite economic advantage. Cost estimates are then made for constructing the two reactors in Japan.

A brief comparison of the C.E.A. and S.S.E.B. stations Bradwell, Berkeley and Hunterston designs, all based on Calder Hall, shows in all cases the departure from the prototype, particularly in the power output offered. The cores are larger, a greater degree of flattening is attained and a high gas pressure increases the heat rating(93). The Berkeley station has been planned for a total installed capacity of 320 MW with a net output of 275 MW. Instead of the four heat exchangers in Calder Hall, the design allows for eight. Provision is made for on-load fuel charging, axial blowers in place of radial, and applications of computer techniques for gas monitoring(94). Design features and essential data are summarized. The design details from the Nuclear Power Plant Co. for the 300 MW Bradwell nuclear power station include civil engineering aspects, pressure vessels, boiler design and

fabrication, Intergron tubing, turbine and blowers, and station layout(95). The English Electric-Babcock and Wilcox design for Hinkley Point is planned for an output of 500 MW; more fuel and higher rating gives a greatly increased output and a reduced unit cost of less than 0.65d(96).

The South of Scotland station at Hunterston in Ayrshire, which is being constructed by G.E.C./Simon-Carves, has been designed for 320 MW. This has been obtained by increased size and charge, and discharge on load from the underside. Details are given of the fuel element charge and discharge operations, unloading the spent fuel into the cartridge-cooling ponds, burst-slug detection, the control-rod system, and overall station control and instrumentation(97). Public local inquiries were held into the siting of Hunterston, the hazards, technical details and cost(98).

Ertaud introduces the French approach to power reactors(99). The experience gained with Saclay P2 and Marcoule G1 has influenced the choice for the design of G2 and G3. More extensive details are given of G1, including the thermodynamic aspects, the plutonium plant and the materials of construction. The G2 and G3 reactors, which are broadly similar in concept to the G1, will produce plutonium and electricity(100).

A design study at Oak Ridge by Smith and others(101) of a 60 MW graphite-moderated gas-cooled reactor utilizes a compact, direct closed-cycle gas turbine system with helium as the working fluid. The core contains uranium and thorium silicides in silicon carbide-silica plate-type fuel elements. The problem of chemical processing is still to be solved.

Gordon and others are concerned with the negative temperature coefficient that is not as large as desirable(102). A study was made of the pressure effect of forcing a liquid metal neutron absorber into the core.

GRAPHITE MODERATED, SODIUM COOLED

At the Atomic International's forum held in November, 1956, papers were read on the Sodium Reactor Experiment covering design, physics progress, operations, component development and fabrication, fuel materials and zirconium problems(103). Siegel(104) examines a sodium graphite reactor for a 75 MW power plant. Improved reactor performance has been obtained by modifying the core design; the fabrication of the moderator elements has been simplified. The design of a 75 MW nuclear power plant has also been studied by Weisner and Sybert at Atomics International(105). The design features of the 75 MW SGR for Consumers Public Power District of Nebraska are described by Gronemeyer and others(106). An enriched uranium core and a thorium-base core have been designed for this(107).

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102. Gordon, B. B., and others. Report BMI–1119. 18 pp.
103. Atomics International. Report TID–7525. 313 pp.
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107. *Engineer*, 203, March 1957, 424–7.

WATER-MODERATED REACTORS

Effective neutron cross-sections for materials in water-moderated reactors are calculated by Brown(108) for light and heavy water at 25°, 80°, 133° and 191°C. Materials are B, Li, Mn, Co, Cd, In, Xe-135, Sm, Eu, Dy, Hf, Au, U, U233, U235, Pu239 and Pu240.

BOILING WATER

Stein and Kasten make a preliminary investigation of boiling reactors(109). Designs of small boiling reactors for power and heat production are studied by Treshow(110). ARBOR is a highly flexible boiling reactor experimental facility to be built at Arco. Fromm and others(111) make a preliminary analysis of design requirements. The reactor is to yield performance and operational data for various light and heavy water, natural and forced circulation boiling reactor concepts over a wide range of temperature, pressure and flow conditions. The AE-6 water boiler of Atomics International has been constructed and tested for use in the power range 0 to 2 kW. Swansom and others give details(112).

A survey has been made of the Argonne Experimental Boiling Water Reactor giving general design details, operating experience, its significance in the development of a power reactor, steam plant power costs, etc.(113, 114).

Construction was commenced in June of the Dresden nuclear power station in Illinois. This is a 180 MW dual-cycle boiling-water reactor using slightly enriched uranium dioxide fabricated as a sintered solid in the form of a cylindrical pellet. Brief discussions are entered on the range of system pressures, sub-cooling and superheating(115, 116). The boiling principle will be used in the Controlled Recirculation Boiling Water Reactor designed by Allis-Chalmers for the Northern States Power Co. Steam will be generated in the reactor at 600 lb/sq. in. and dropped to 540 lb/sq. in. for delivery to a 60 MW turbine, power being regulated by controlling the rate of water circulation through the core(117).

In Germany, near Frankfurt-on-Main, a closed-cycle boiling-water reactor was under consideration which would give a thermal output of 58 MW supplying a 17 MW turbine. Coles(118) examines the design and constructional details of the RWE-Atomkraftwerk Kahl using saturated steam instead of taking it from an oil-fired superheater. A technical description of the proposed plant is given in *Nuclear Engineering*(118).

PRESSURIZED WATER

The operational problems of start up, shut down, maintenance and the refuelling of the PWR plant has been discussed by Jones and Witzke(119). The preliminary operation of Shippingport will involve about 60 formal tests over a period of about nine months. Parrish(120) describes the methods to be adopted and the problems involved in inspection, checking and testing. Bickel and others give details of the thermal and hydraulic analyses of the PWR core(121). Indian Point and Yankee are two pressurized-water reactors which are being applied commercially to electric power production. Indian Point is the first commercial converter-type unit for which thorium is planned to supplement the U235. Full power operation of 236 MW is expected by May, 1960. With the addition of superheat the cost of $322/kW is reduced to $233/kW. Yankee is a 134 MW design fuelled with uranium dioxide.

The main objective is to make the PWR nearly commercially competitive with conventional-type steam plants without sacrificing any of the inherent safety(122). A survey is presented of the pressurized-water reactors available for the World markets(123). Van der Spek gives technical and economic reasons for choosing the PWR for the first Belgian 11.5 MW pilot plant(123a). Pressurized ordinary water reactors will power the Russian 420 MW station, using water as coolant and moderator and slightly enriched uranium for fuel. Each of two units will have a reactor feeding three 70 MW turbo-generators(124).

HEAVY WATER MODERATED

Canadian experience with the natural uranium heavy-water reactor for the attainment of low-cost power is described by Lewis(125), including power output data and cost estimates. An interim report has been issued on the 20 MW Nuclear Power Demonstration, Canada's first nuclear power station, which is scheduled for start-up by mid-1959(126). The plant is to be owned jointly by Atomic Energy of Canada Ltd. and Ontario Hydro, the latter to operate the entire plant as part of its generating system.

McGloska(127) considers that the heavy-water reactor has promise. Design studies indicate that the estimated cost of power is 1.31 cents/kWh for a 60 MW plant and 1.54 cents/kWh for a 40 MW unit. The slightly enriched fuel is mixed with thorium as an oxide.

A design and feasibility study for a helium-cooled version was made at Oak Ridge by Dahlberg and others(128). The fuel element allows the heavy water to be kept at a low pressure with a high exit gas temperature.

THE PACKAGED POWER REACTOR

The APPR-I went critical on April 8, 1957, and generated electricity one week later. The 700-hour test was completed on July 2 and showed response to load demand, stability exceeding expectations. It is a 1.9 MW(E) water-moderated and cooled reactor using highly enriched uranium oxide. Alco Products Inc. released to the technical Press an extensive amount of design and constructional data. Several summaries have appeared which also examined the feasibility of small nuclear power plants for remote bases(129). Kasschau reports on the problems encountered in the design, fabrication, construction and early operation, and gives details of the design which makes it suitable for use in advance bases, as the only means of providing the requisite power(130).

Details of the critical experiment are given by Williams and others(131), whilst Oby and Gallagher(132) interpret the experimental flux and power data.

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109. Stein, J. M., and Kasten, P. R. Report ORNL–1062. 66 pp.
110. Treshow, M. Report ANL–5327 (Del.). 63 pp.
111. Fromm, L. W., and others. Report ANL–5761 (Rev. 1), 159 pp.
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113. *Nucleonics* Reactor File No. 1. *Nucleonics*, **15**, July 1957, 53–64.
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115. *Engineer*, **204**, Sept. 27 1957, 470–3.
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126. Report AECL 356. 48 pp.
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131. Williams, D. V. P., and others. Report ORNL–2128. 83 pp.
132. Oby, P. V., and Gallagher, J. G. Report APAE–Memo–2a. 15 pp.

BERYLLIUM MODERATED

The B.R.F. reactor of the U.S.S.R. Academy of Sciences has been briefly described by Krasin and Dubovsky(133). This was constructed to determine the physical parameters of a beryllium-moderated pile. The total weight of the beryllium blocks, each $16 \times 16 \times 4$cm, was 12,000 kg.

HOMOGENEOUS AQUEOUS

Kasten and others(134) define the problems associated with an aqueous research reactor to give high thermal and fast neutron fluxes. Results are given of a preliminary investigation for producing a thermal flux of 5×10^{13}n/cm^2-sec.

The HRE was the first homogeneous reactor to be constructed at Oak Ridge and was dismantled in 1954 after two years of successful experimental operation. Uncertainties resolved included nuclear and chemical behaviour at the high temperatures and pressures necessary for power generation. HRT, the second of the series, is a two-region, forced-circulation type operating on a thorium-U233 breeding cycle. Complete design details of the Homogeneous Reactor Experiment (No. 1) are presented by Segaser and Zapp(135). Shield design and steam activity calculations are analysed(136). Robertson reports on a study of the steam power cycle and equipment both for the HRE pilot model and for a full-scale homogeneous reactor. A summary is added of steam power station costs and trends(137). Experimental investigations by Visner and Wood on low-power criticality confirm theoretical predictions (138).

The problems of gas removal in the high-pressure system of the Homogeneous Reactor Test were studied by Spiewak and Falkenberry(139). Their report includes investigations of the stability of the fuel-solution in a circulating system, the corrosion rate and the behaviour and removal of corrosion and fission product solids. The design data of the HRT considered by Zapp and Aven included the core solution, main fuel loop and components, heat exchangers, main blanket loop and components(140). Kasten investigated the dynamics of the reactor(141).

A design and feasibility study has been made of the boiling homogeneous reactor for power and U233 production(142). Fax summarizes the principal design parameters of the proposed Westinghouse 80 MW plant(143). Johnson and Fox outline the features of the Pennsylvania Advanced Reactor Project which is intended for experimental and analytical studies leading to the design of an aqueous H.R. plant of 150 MW by 1962(144). Kenton(145) comments on design development and the results of loop tests. Further evaluation of the design and economic aspects of this type of reactor came from the Babcock and Wilcox and Nuclear Power Group(146).

In Britain, Hurst, Wells and Newby consider that in many important respects the homogeneous aqueous reactor showed substantial advantages over other types(147). They examine the Oak Ridge Experiment and the Homogeneous Reactor Test and continue to a study of a 100 MW breeder reactor pointing out the type of problem still to be solved if this reactor is to fulfil its place in producing low-cost power.

LIQUID METAL AND FUSED SALT

Mars, Inglima and Schomer(148) have made a preliminary study of a 550 MW LMFR power plant using a circulating fuel solution of U233 dissolved in bismuth and a breeder fluid of thorium bismuthide dispersed in bismuth. Power costs based on both single plants and multiple units utilizing common chemical processing facilities range from 6.5 to 8.5 mills/kWh. The value of certain thermodynamic functions were determined experimentally by Egan and Wiswall(149) by a high-temperature galvanic cell method. Examples are given of the application of thermodynamic data to reactor technology and fuel processing. The Dow Chemical Co. outline their programme for the design and development of a commercial reactor whose basic structure will follow the SGR but adapted for use with liquid metal fuel together with a blanket(150). Operation is scheduled for 1958.

An intermediate energy reactor where the fuel-bearing fused fluoride salt functions as neutron moderator and heat transfer medium was the subject of a feasibility study by Davies and others at Oak Ridge(151). Fission heat is transferred to a sodium loop, thence to another sodium loop which is non-radioactive, generating superheated steam at 1,000°F. The net thermal plant efficiency of the design is 38.2% at 229 MW electrical.

ORGANIC MODERATED

Fricke(152) studies the basic nuclear characteristics of diphenyl moderated and cooled reactors with an average operating temperature of 600°F. Calculations for different types of reactors are determined with power levels ranging from 0 to 140 MW. A 12.5 MW facility is described by Starr to produce power at about 16 mills/kWh, which could be reduced by increasing the output to 150 MW(153). A forum was held in November, 1956, by Atomics International which included discussions of the design, construction, progress, research and economics of the OMRE(154).

The most important phases of the work done during the past five years or more on the technology of organic reactor moderators and coolants has been consolidated(155). The Organic Moderated Reactor Experiment became critical in September. The main design features are summarized(156).

The British attitude to this type of reactor is presented by Bowker(157) who analyses the design and materials features, including the advantages and disadvantages of using organic liquids particularly from the point of view of ship propulsion.

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135. Segaser, C. L., and Zapp, F. C. Report TID–10082. 412 pp.
136. Segaser, C. L. Report CF–52–2–12. 85 pp.
137. Robertson, R. C. Report CF–50–1–93. 86 pp.
138. Visner, S., and P. M. Wood. Report ORNL–1858. 97 pp.
139. Spiewak, I., and Falkenberry, H. L. " Advances in Nuclear Engineering." Vol. 2 (Philadelphia, N.E.S. Congress).
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142. Zeitlin and others. Report CF–54–8–240. 174 pp.
143. Fax, D. H. (ed.). Report WIAP–9. 46 pp.
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150. Report DOW–NR–55001–1–S. 210 pp.
151. Davies, R. W., and others. Report CF–56–8–208 (Del.). 249 pp. (Summary: *Nucleonics*, **15**, Aug. 1957, 64–5.)
152. Fricke, E. F. Report ANL–5457. 56 pp.
153. Starr, C. World Power Conf., Belgrade, Paper B3/5.
154. Atomics International. Report TID–7525. 313 pp.
155. Atomic Energy Commission. Report TID–7007. 248 pp.
156. *Nuclear Engng.*, **2**, Dec. 1957, 521–5.
157. Bowker, H. W. *Nuclear Power*, **2**, Nov. 1957, 473–7.

SHIP PROPULSION

The application of nuclear propulsion to merchant ships was extensively covered in Washington at a symposium attended by representatives of the A.E.C., the Maritime Commission and U.S. industry. Papers were read on insurance, gas-cooled reactor concepts and research development, the closed-cycle boiling-water reactor, the organic-cooled and moderated reactor, nuclear-propelled passenger cargo ships, and the 20,000-s.h.p. tanker system(158).

Hinton and Moore(159) review future trends of power-driven ships against an historical background followed by a discussion of the characteristics of the pressurized water and the graphite moderated gas cooled reactors. A gas cooled reactor of high rating designed for the propulsion of a supertanker is considered. Economics of operation are compared with a conventionally-powered vessel. Current reactor types having potential merit are considered and the conclusion reached is, that while nuclear power units of 20,000 to 25,000 s.h.p. with competitive

economic performance could be designed in the next few years, reactors for smaller ships have yet to be developed.

Godwin(160) discusses the possibilities of nuclear propulsion within the next 10 years thereby improving the earning capacity of a number of ship types, including tankers, bulk carriers and possibly liners. Smith and Richards(161) present a broad view of the present state of development in nuclear propulsion for merchant ships indicating the technical and economical problems remaining. Fuel cycles and costs are compared and the advantages and disadvantages of basic reactor designs are reviewed. They describe the results of a study for a 47,000-ton single-screw tanker for which gas-cooled heavy water-moderated reactors fuelled with natural uranium might be feasible.

The De Laval Memorial Lecture of 1957 was given by Brown of Pametrada and dealt with the propulsion of ships by steam turbine machinery. A large part of his thesis is concerned with nuclear marine propulsion. Comparison is made between graphite-moderated, pressurized-water and heavy-water gas-cooled reactors(162). Bauer and Kendon(163) inquired into the optimum combination of size, shape and speed of ships and consequent relation to propulsive power. They discuss the theory of the effect of the " below-the-load " waterline part of a ship's hull on performance, the ship's resistance due to the formation of waves and the power requirements. They estimate the operating costs of an oil tanker of 100,000 tons d.w. and the use of a modified graphite-moderated gas-cooled natural uranium reactor.

Kenton(164) summarizes the programme of the U S. Navy for the complete conversion of the combat fleet to nuclear propulsion. From 1948, when the submarine reactor project was formally established, to 1966, when the Navy's sixth nuclear aircraft carrier was expected to be commissioned, half the programme is likely to have been completed. It is feasible that by that time 45 submarines may be included, in addition to 6 guided-missile cruisers and the beginning of a flotilla of destroyers. A summary is given of the design and performance features of the U.S. submarine " Nautilus "(165).

The greatest single problem that has resulted from the development of nuclear propelled merchant ships is the safety aspect. Fayram and others(166) outline some of the potential hazards that exist, emphasizing the release of radioactivity in various bodies of water. Safety requirements on board a nuclear propelled tanker are discussed by Ertaud(167).

The technical problems associated with the use of gas turbines for nuclear ship propulsion have been considered(168). Bammert studies the optimal pressure ratios with the use of different working fluids in closed-cycle gas turbines. The characteristics of closed-cycle gas turbines with gas-cooled reactors are included. Design study contracts for closed-cycle gas turbine propulsion plants with gas-cooled reactors have been placed with the Cleveland Diesel Division (General Motor Corp.). Giblon and Kurz(169) describe in detail the first complete design for a 20,000-s.h.p. tanker including the arrangement of auxiliaries, safety aspects and the utilization of waste heat from the main engines. Keller(170) summarizes the achievements made during the past five years in the design and operation of closed-cycle gas turbine power plants.

The application of nuclear power to aircraft is considered by Porter(171) especially to designs that will give the advantage of almost unlimited endurance at high speeds. He studies the size of the reactor required, the design, heat transfer problems, choice of coolants, stability, shielding and crash hazards. The problem of using nuclear power for aircraft propulsion is the crucial one of reliability in freedom from shut-down periods. This factor is likely to strongly influence design and operation. Dunworth (172) considers that the feasibility of power from a single reactor is a matter of opinion. There is the problem of avoiding xenon poisoning on landing for a short stop, as well as the large weight. He indicates the nature of experimental programmes that are necessary for the development of nuclear propulsion. Ohlinger outlines the features of heavily shielded reactors that will supply heat to turbojets or turboprops from relatively small amounts of fissionable fuel. Huge size, maintenance and operation are among the problems to be resolved(173). The nuclear powered aircraft is explored by Johnson and Cleveland(174) almost exclusively from the point of view of the airframe designer.

An Aircraft Reactor Experiment was constructed at Oak Ridge and operated in 1954. This reactor is a circulating fuel, very high temperature type, using molten fluoride fuel, beryllium-oxide moderator and sodium for removing the heat from the reflector. Weinberg(175), in describing the experiment, confirms the view that chemical reactor systems merit serious investigation and that economic power can be achieved in possibly the simplest manner by burning U235 in very high temperature devices with fuels in liquid form. The Russian nuclear powered aircraft project is briefly discussed by Povronsky(176).

158. U.S.A.E.C. Report TID–7539. 190 pp.
159. Hinton, Sir C., and Moore, R. V. Inst. Marine Engrs. preprint. Nov. 1957. (In: *Engineer*, **204**, Nov. 29 1957, 774–8.)
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164. Kenton, J. E. *Nucleonics*, **15**, July 1957, 66–71, 126.
165. *Nuclear Engng.*, **2**, Nov. 1957, 455–6.
166. Fayram, R. A., and others. *Nucleonics*, **15**, May 1957, 109–111.
167. Ertaud, A. *Atomkern Energie*, **2**, Aug./Sept. 1957, 299–302.
168. Illies, K., Bammert, K., and Junkermann, W. *Atomkern Energie*, **2**, Oct. 1957, 368–389.
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170. Keller, C. A.S.M.E. Trans., **79**, April, 1957, 627–43.
171. Porter, W. H. L. *Atomics*, **8**, Jan. 1957, 7–14.
172. Dunworth, J. V. *Atom*, **12**, Oct. 1957, 6–10.
173. Ohlinger, Lee A. S.A.E. paper. Jan. 1957.
174. Johnson, C. L., and Cleveland, F. A. *Aero. Engine Rev.*, **16**, June 1957, 48–57.
175. Weinberg, A. M. *Engineering*, **184**, Nov. 8 1957, 604–5.
176. Povronsky, G. *Missiles and Rockets*, **11**, June 1957, 54.

RADIATION HAZARDS AND PERSONNEL PROTECTION

The report of the British Insurance (Atomic Energy) Committee studies insurance problems associated with the development of nuclear energy(177). A brief survey is given of types of reactors and atomic fuels with the emphasis on essential features of safety in design operation. It outlines associated hazards. A code of safe operational practice is recommended, the sole responsibility for danger and injury to be the owners'.

Murphy, Ball and Gibbs, in the U.S.A., make recommendations for a national governmental programme for the financial protection against atomic hazards(178). The accident record and safety precautions made by the A.E.C. are outlined by Hayes(179). The Congressional Joint Committee on Atomic Energy studies the A.E.C. procedures and organization for the licensing of reactor facilities(180). Fischerhof presents the German aspect of protection and liability. He reviews the problems likely to be encountered when drawing up the German Atomic Energy law(181). Points covered are the protection of, and liability to, the community, security and safety, a supervision system, protection against radiation and complete breakdown, and various aspects of liability.

Alexander(182) describes scientific aspects of the biological changes produced by atomic radiation. The hazards are set in true perspective. According to Whipple(183) the maximum permissible occupation exposure recommended is 0.3 roentgen per week, that is a three-year reduction in life span if exposed at this level throughout a working lifetime. Reactor plants can be designed and operated with an average level of less than 0.3r per week.

An international symposium was held at Harwell on Glove-box design and operation at which papers were read on safety aspects, general design installation and maintenance, and applications(184).

General Electric's Hanford policies and procedures are reviewed in respect of control of hazards during work with radiation and radioactive materials(185). The problem of maintenance on radioactive aircraft components by remote control is investigated by Marjon and Kress of Convair(186). Giannelli describes the radioactive contamination monitor for the C.I.S.E. metallurgical plant in Italy which has been in operation for over a year(187).

REACTOR SAFETY

After brief considerations have been given of safety requirements, Boadle outlines(188) the characteristics of reactors which might result in accidents including transient behaviour with reactivity changes, changes in neutron balance with time, temperature effects, and power reduction. He groups the accidents which might occur into incidents arising from an uncontrolled power explosion, incidents resulting from a failure of the cooling system, and incidents which involve the rupture of the reactor container of the primary cooling circuit.

The growing high power levels that have been proposed for many new reactors have increased the concern about the hazards from radioactive materials which might possibly be released in reactor accidents. Burnett(189) shows that these hazards do not necessarily increase with power level because of compensatory factors in the design. Kasten and Rosenthal investigate the safety of one-region and two-region reactors for the case where cooling of the core fluid has resulted in reactivity addition(190).

A series of reactors have been built or have been designed for investigating special power excursions where reactor transient behaviour and safety are to be studied for heterogeneous light water-moderated and enriched fuel reactor systems. Wilson (191) describes the engineering facilities of SPERT-1, which is an open vessel into which

has been placed initially a plate-type uranium and aluminium core with no provision for heat removal or coolant circulation. A preliminary design is presented for SPERT-III which is a development of the initial facility(192). The reactor and primary coolant system are designed for operation up to 2,500 p.s.i. and 650°F. Coolant flow rates up to 20,000 g.p.m. are obtained with heat removal capacity sufficient for 60 MW over a period of about 30 minutes.

A number of features are outlined by McCarthy and McMath to safeguard investment in the fast-breeder-reactor power plant. A decision was made to enclose the radioactive portions of the plant in a gas-tight building so that a final barrier could be provided between the public and the reactor. Criteria are developed for locating the reactor on a safe and economically suitable site(193). Porzel analyses the safety aspects of the A.N.L. Boiling Experimental Reactor with regard to internal explosion(194), and considers the theory and design of a blast shield which makes use of the properties of various materials, ranging from Celotex to concrete in order to reduce the shock wave impulse.

The Committee of Inquiry on the Windscale accident reports on the cause of the accident and the measures taken to deal with it. It occurred during a routine maintenance operation, the release of the Wigner energy from the graphite(195). As a result of the accident a committee was appointed by the Prime Minister to determine the organization of certain parts of the U.K.A.E.A. Recommendations include increase of staffs at all levels(196).

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182. Alexander, P. "Atomic Radiation and Life." Penguin. 1957. 239 pp.
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187. Giannelli, G., and others. *Energia Nucleare*, 4, Feb. 15 1957, 24–32.
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191. Wilson, T. R. Report IDO–16318. 43 pp.
192. Wilson, T. R. Report IDO–1634. 31 pp. (Summary: *Nucleonics*, 15, Aug. 1957, 68–71.)
193. McCarthy, W. J., and McMath, F. C. A.S.M.E. Trans., 79, Jan. 1957, 41–6.
194. Porzel, F. B. Report ANL–5651. 108 pp.
195. Command Paper 302. H.M.S.O. 26 pp. (Summary: *Nuclear Engng.*, 2, Dec. 1957, 510–2; *Atom.*)
196. Command Paper 338. H.M.S.O. Dec. 19, 1957.

REACTOR CONTROL

Salmon(197) discusses reactivity, neutron life-time and delayed neutrons and their relationship with the rate of change of neutron density and reactor power. Amounts of reactivity and various components are reviewed and an outline is given of physical methods of reactor control. The basic issues that dictate the design of control systems are considered by Van Rennes and others(198).

The control of reactors based on movable poisons is discussed by Anderson and Dunning(199). They deal with materials using boron, hafnium and three of the rare earths as the active materials. Europium oxide dispersed in stainless steel or titanium yields a control rod singularly free of radiation damage. The oxides of the rare earths have good properties for reactor control materials. Dayton(200) studies empirical methods for computing the effectiveness of control-rod materials with a margin of error to about 2%. The standardization in the nuclear reactor field, with particular reference to control drive mechanism has been considered by Rolan and Hinrichs(201). A universal type of mechanism has been developed which can be adapted to a variety of research and power reactors.

The Scottish nuclear power station at Hunterston is compared with the conventional power station. Smith(202) describes the control system, safety arrangements, and control-rod operations. Beaver and others(203) present the final specifications of the stainless steel fuel and control-rod components which have been developed for service in the 10 MW APPR-1. In control-rod experiments on this reactor, Fairbanks and Gallagher(204) treat partially and fully inserted control rods.

The control system of DIDO uses a cadmium neutron absorber. Newman(205), gives details of each group in the system: the coarse control shut-off units of the signal-arm type, a single fine control or regulating rod, and two safety rods providing additional absorption which are releasable by gravity. Hutter(206) gives details of the engineering design of the control sub-assembly and drive mechanism for the fast reactor EBR-II. Zulliger(207) gives similar information for the HRE.

Canadian reactors are much more dependent on their control system because of high rating, resultant high flux and considerable xenon build-up after shut-down. Siddall(208) describes the adoption of a new control philosophy which replaced the serious shortcomings of the earlier type of protective channels. Lennox and Pearson give a general description of automatic control system of NRX(209). The problems in the control of sodium-cooled graphite-moderated reactors were reviewed by Owens covering nuclear instruments, safety problems, power control and steam pressure control(210). A general description is given of the measurement systems, circuits and other components of the control system of Belgium's first nuclear reactor, BR1(211).

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202. Smith, R. J. *G.E.C. Atomic Energy Rev.*, March 1957, 39–45. (Also: *Elec. Energy*, 1, May 1957, 274–8.)
203. Beaver, R. J., and others. ORNL–2225. 41 pp.
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206. Hutter, E. "Advances in Nuclear Engineering," Vol. 2.
207. Zulliger, A. Report CF–52–3–36. 32 pp.
208. Siddall, E. *Nucleonics*, 15, June 1957, 124–9.
209. Lennox, C. G., and Pearson, A. Report CREL–698. 16 pp.
210. Owens, J. E. "Advances in Nuclear Engineering," Vol. 2.
211. "A.C.E.C. Rev.," No. 1, 1957, 2–34.

RADIATION SHIELDING

An outstanding contribution this year has been made by Price, Horton and Spinney(212). Henderson and Whittler's handbook on the NRU reactor(213) deals in particular with calculations on the thermal flux, heat production in top and bottom thermal shields, design features of the bulk shield, activities produced in the heavy water, shielding requirements of the main heavy water circuit, etc. Tables are included of gamma and neutron absorption in a variety of materials.

In a study of the materials for biological shielding Glen(214) reviews the properties, characteristics, costs and other considerations for several types of metallic, organic and concrete shields. Vernon(215) has made computations to determine radiation leakage from the biological shield of the Sodium Reactor Experiment. The calculations and approximations used are probably adequate for the analysis of most large stationary reactors but may only be suitable for preliminary estimates where mobile reactors are concerned.

Laurence(216) makes an introductory study on the design of shielding and includes consideration of choice of materials, dimensions, nuclear reactions affecting penetration, the heating of the shielding and the production of radioactivity in the coolant. He argues that the use of very complex theory and laborious calculations have little advantage and advocates the use of approximate methods. Brown and Engholm measure neutron attenuation in shield materials(217).

212. Price, B. T., and others. "Radiation Shielding." Pergamon Press. 350 pp. (International series of monographs on nuclear energy.)
213. Henderson, W. J., and Whittler, A. C. Report–578 (Rev.). 507 pp.
214. Glen, H. M. "Advances in Nuclear Engineering," Vol. 2.
215. Vernon, A. R. Report NAA–SR–1949. 26 pp.
216. Laurence, G. C. *British Nuclear Energy Conf. Jnl.*, 2, Jan. 1957, S54–S59.
217. Brown, W. W., and Engholm, B. A. Report NAA–SR–Memo–1143. 38 pp.

NUCLEAR ENGINEERING IN GENERAL

The 1957 Review of British Industry applied to the atomic field consisted of 48 articles dealing with various facets of nuclear power development(218). Reviews include the survey of world energy needs and progress, the requirements, progress and development in Europe, the U.K. and U.S.A., the scope in under-developed countries, economics and costs, etc. Oswald(219) gives a general account of the grouping of companies in this country for general nuclear power development.

The 43rd Thomas Hawksley lecture was given by Gibb on engineering problems connected with the industrial application of nuclear energy(220). He discusses the need for the nuclear physicist and the turbo-generator designer to work closely at every stage of design and development and advocates close co-operation between scientists and engineers for the equipment in between, including circulators, ducts,

boilers and auxiliaries. Detailed consideration is given of the engineering problems inherent in designing reactors, fuel elements and refuelling and components from the Calder Hall-type point of view are discussed. Draper(221) indicates the complexity of maintenance problems in various reactor systems. The easiest systems to operate and maintain are those permitting the use of conventional tools and techniques. He lists reactor power plant types, arranging them in order of increasing difficulty of maintenance indicating advantages and disadvantages.

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Technical Papers and Publications

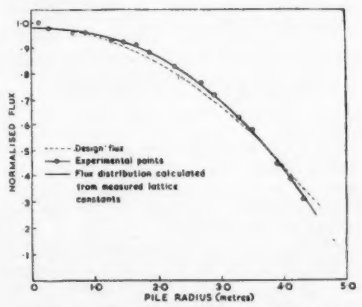
Symposium on Nuclear Energy

(The Institution of Chemical Engineers, in conjunction with the B.N.E.C.)

Commissioning and Operation of "A" Station Calder Works. By H. G. Davey, O.B.E., M.Sc. (Works General Manager, N.W. Area, U.K.A.E.A.I.G.)

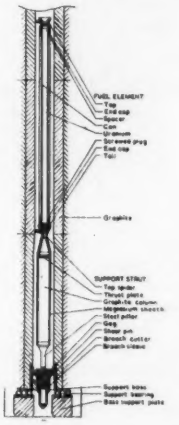
THE commissioning period from May, 1956-August, 1957, was relatively short and measurements required were divided into two groups, desirable and essential, the latter only being taken. It was essential to determine the critical size of the reactor and the optimum disposition of control rods, and information obtained on No. 1 reactor was of considerable assistance in commissioning reactor 2, which was the subject of a more detailed experimental programme.

Critical mass of the reactor was checked by loading the fuel in the form of a cylinder and estimating the negative reactivity of the system while sub-critical by BF_3 counters using a neutron source (antimony beryllium) located at the centre. Additional neutrons were produced by fission as loading progressed and it was possible to extrapolate the curve of neutron count-rate against channels loaded to obtain the critical mass. The design had been slightly on the pessimistic side after Windscale experience (when 1,768 channels were required against 700 estimated) and the critical mass was, in fact, 406 channels against 475 estimated, or within reasonable error limits.



Flux distribution in the Calder reactors.

The other lattice constants having been measured and calculated, the control rods were installed and calibrated. It had been estimated in the design stage that 70 control rods might be required. After the critical mass had been assembled, 26 control rods were fully inserted and the neutron flux measured as further fuel channels were loaded. It was found that the fully-loaded reactor of 1,696 channels was very slightly sub-critical in this condition, and since the excess reactivity of the system without control rods could be estimated from the initial loading experiments it was possible to estimate the neutron absorption of the control rods. Forty-eight rods were finally decided upon. Calibration of the control rods was effected by varying the air pressure, the nitrogen present acting as a neutron absorber, to balance the withdrawal of the rods. Following control rod calibration, gas-flow tests were made with recording vane anemometers in each individual channel to check agreement with the design value, obtained by means of gags of sizes dictated by the heat generation in the channel, proportional to the neutron flux distribution in the core.

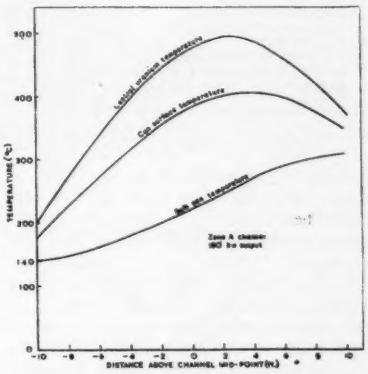


Section of fuel element channel.

Gas Tests

Charging with CO_2 to full pressure was the next step, followed by leak detection and stoppage. The initial leak rate was approximately 100 lb/hour, which was halved by simple tightening or re-packing of valve joints and glands, particularly in the smaller auxiliary circuits.

The blowers were then run for several days to subject the gas circuit to normal aerodynamic forces and show up any flaws in design and construction, so that any modifications necessary could be easily carried out while the plant was still virtually inactive. It also gave the blowers running tests at normal load, and provided training for the operators. Gas pressure was then reduced to near atmospheric and the charge/discharge gear tested. Blowing-off of CO_2 was also investigated with observers and detection equipment located down-wind from the stacks; no appreciable amounts were detected with cold CO_2 at high discharge rates and unfavourable atmospheric conditions. The gas circuit was then completely purged with air and two days spent in meticulous inspection of the whole of the gas circuit and its contents. The only apparent damage was that a number of fuel elements had their top attachments loosened; a matter of importance since the function of this is to enable the element to be grabbed by the discharge machine. The uppermost cartridges in each channel had their tops fixed by expanding the stud with a hammer and punch, this operation being carried out inside the pressure vessel. (It was later discovered that about 90% of these slackened off again and they were removed and welded.)



Variation of central uranium can surface, and bulk gas temperatures along channel.

The burst slug detection gear was tested by the use of uranium foils, to give fission product activity signals under low-power conditions similar to a small can leak at full power, in certain channels, and operating at reduced power. A modification found necessary was the installation of a small feed of inactive coolant gas to the sampling gear to minimize the high background activity produced by argon-41.

The detection gear for the ducts was then calibrated using foils in the ducts and fairly high power operation. This test was kept until last, when no further entry to the pressure vessel was required.

Working-up

The reactor was evacuated and filled with CO_2 several times to reduce the air content to about 0.2% by volume, after which the system was pressurized. The system was then heated to 140° C before

Table 1—Operating Conditions at "A" Station

	17 Oct. 56	30 Oct. 56	5 May 57	Design
Max. cartridge surface temperature	707° F. (375° C.)	707° F. (375° C.)	766° F. (408° C.)	766° F. (508° C.)
CO_2 temperature at heat exchanger inlet	569° F. (298° C.)	578° F. (303° C.)	624° F. (329° C.)	637° F. (336° C.)
CO_2 temperature at heat exchanger outlet	273° F. (133° C.)	287° F. (142° C.)	273° F. (134° C.)	275° F. (135° C.)
CO_2 pressure	100 lb./sq. in. g.	97 lb./sq. in. g.	99.1 lb./sq. in. g.	100 lb./sq. in. g.
CO_2 flow/heat exchanger	460 lb./sec.	579.5 lb./sec.	500.5 lb./sec.	491 lb./sec.
Steam conditions				
H.P. steam flow per H.E.	67 700 lb./hr.	83 500 lb./hr.	95 800 lb./hr.	99 000 lb./hr.
H.P. steam pressure	162 lb./sq. in. g.	160 lb./sq. in. g.	185.5 lb./sq. in. g.	195 lb./sq. in. g.
H.P. steam temperature	545° F.	542° F.	592° F.	595° F.
L.P. steam flow per H.E.	23 650 lb./hr.	36 400 lb./hr.	27 800 lb./hr.	29 650 lb./hr.
L.P. steam pressure	48.4 lb./sq. in. g.	45 lb./sq. in. g.	67.5 lb./sq. in. g.	48 lb./sq. in. g.
L.P. steam temperature	352° F.	350° F.	367° F.	350° F.
Feed water temperature	71° F.	70° F.	67° F.	100° F.
Reactor power	137 MW	170 MW	180 MW	180 MW
Electrical generation	28 MW	37 MW	42 MW	42 MW

nuclear operation commenced by injecting steam into the heat exchanger drums. While heating was in progress, the overall temperature coefficient of the reactor was obtained. Working-up began on August 1 when the first steam was generated and passed to the dump condensers and power was increased until a fuel element temperature of 300°C was obtained, with a thermal power of about 60 MW. It was found that, in certain areas, where auxiliary cooling circuits passed through shielding walls and around the spindles of the main inlet valves, relatively high radiation levels were obtained, necessitating additional shielding. At this point a deliberate trip was carried out to study system behaviour and enable the appropriate operating procedures to be compiled.

Maximum fuel element temperature was increased to 350°C on August 6, and blower speed increased to give 130 MW output, when safety valves were floated. Turbine commissioning was commenced during the third week in August.

The design outlet temperature was not being achieved with maximum specified element temperatures. This necessitated an increase in blower speeds and made it difficult to hold down the gas return temperature to 140°C, with resultant overloading of the heat exchanger L.P. system. On October 18, following the official opening by H.M. The Queen, the power was raised to 170 MW (heat) at maximum blower speed, these conditions being maintained until November 5 when a scheduled shut-down took place for discharge of experimental cartridges. A further shut-down took place in February when the channel flow pattern was adjusted by changing gag sizes, and new fuel cartridges were fitted with Magnox braces to prevent bowing.

Reactor 2

The commissioning of reactor 2 began in December, 1956, and it was in full operation by February, 1957. It is pointed out that most of the teething troubles which occurred were on the more conventional items of equipment.

The next phase is to review certain minor modifications which will increase output, and to consider simplification and re-grouping of instruments.

Table 1 gives comparison between design figures and those obtained at three different times during the commissioning period.

The development of the Butex process for the industrial separation of plutonium from nuclear reactor fuels. By C. M. Nicholls, B.Sc.(Eng.), F.R.I.C. (Chemical Engineering Division, A.E.R.E. Harwell).

The Butex process was developed at Chalk River from 1947 onwards, and the paper reviews the engineering problems met with in pilot plant working. At the time it was the first continuous radioactive solvent extraction plant to be built and operated outside the U.S. The author points out that although later processes have tended to supersede this process, many of the accepted standards stem from this original work.

Fission Product Disposal. By K. Saddington, M.Sc., F.R.I.C. (Deputy Head of Laboratories R. and D. Branch, U.K. A.E.A. I.G. Windscale).

The magnitude of the problem facing the industry in the disposal of active wastes was reviewed and a survey of possible future methods was made. Long term work in the U.S. and the U.K. is directed towards high temperature separation processes which do not involve aqueous solutions.

This, however, is regarded as an ideal, and current activity is directed towards the development of a separation process that gives such complete removal of fission products at the first stage that the subsequent raffinates have negligible activity, all the activity being confined to the highly active waste. A salt-free separation process is another aim; this would enable the medium active raffinate to be evaporated by a large factor so that the condensate could be discharged to sea virtually free of activity.

The Marcoule plutonium plant. By R. Galley (Commissariat a l'Energie Atomique, Paris).

No advance information was available on this paper at the time of going to press but it was understood that full details of the Marcoule plant would be given.

Nuclear Criticality—A Novel Factor in the Design and Operation of Chemical Plants. By C. M. Nicholls, B.Sc.(Eng.), F.R.I.C. (A.E.R.E. Harwell), and A. H. C. P. Gillieson, B.Sc., Ph.D. (U.K.A.E.A. Risley).

This paper reviewed the methods of achieving safety from unwanted criticality by geometrical methods, it being emphasized that complex systems may not always be composed of an assembly of simple basic shapes. Particular emphasis was placed on the utilization of intrinsically safe designs of plant rather than limitations in process operation.

Control of criticality by limitation of the amount of material present can place a severe analytical load and operating responsibility on the plant management, and should be resorted to only when intrinsically safe methods are not possible.

Fuel Processing in Homogeneous Aqueous Reactors. By I. Wells, B.Sc., D.I.C. (Chemical Engineering Division, A.E.R.E., Harwell), and E. Lofthouse, B.Sc., M.Sc., Ph.D. (Widnes Laboratory, I.C.I. Research Department).

The special processing problems of the homogeneous reactor are discussed, with particular reference to the two-zone breeder reactor.

A computation of the performance of a multi-component solvent extraction system. The separation of uranium and plutonium from fission products by tributyl phosphate. By J. T. Wood, Ph.D., and J. A. Williams, B.Sc. (both of R. and D. Branch, U.K. A.E.A. I.G. Windscale).

Problems concerning immiscible phases can be solved by graphical methods. This paper showed how these methods could be applied to complex multi-component solvent extraction systems.

CORRESPONDENCE

Dear Sir,

We notice in the brief report of our paper "High Boron Alloy Steels," appearing on page 30 of the January issue of *Nuclear Engineering*, an error regarding an essential feature of the paper.

This appears towards the end of the first paragraph where we are reported as saying ". . . results showing an increase in forgeability with Al content up to a maximum of about 2%." This is liable to give a most misleading impression of the results we have reported in our paper. A correct statement would read as follows: ". . . results show that for a given Boron content up to 4.75%, there is an upper and lower critical aluminium content for forgeability."

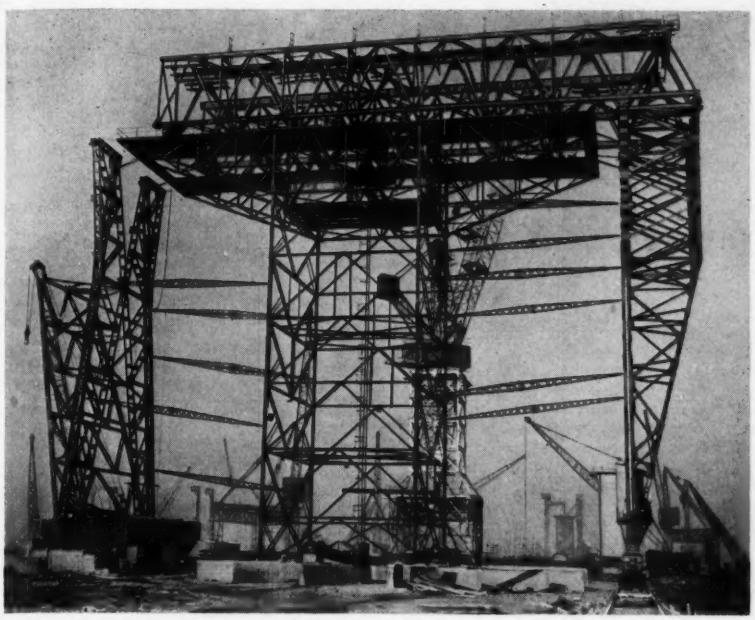
We should be most grateful if you could draw your readers' attention to this error and our corrected statement.

Yours faithfully,

E. W. Colbeck.

(Director, Hadfields Ltd.)

(Our apologies for the error. Ed.)



On the Bradwell nuclear power station site in Essex the 200-ton capacity Goliath crane nears completion. This photograph was taken mid-December, eleven months after ground was first broken by the contractors, Nuclear Power Plant Co., Ltd.

World News

International

Although the Euratom treaty came into operation on January 1, at the time of going to press no final decision had been made about the future headquarters of the organization. M. Louis Armand, of France, one of "the three wise men" becomes president of Euratom and Signor E. Medi, of Italy, vice-president.

European Nuclear Energy Agency will come into being on February 1 within the framework of the O.E.E.C. The Agency will promote the establishment of joint undertakings between countries in Western Europe, discuss their research and production programmes for nuclear energy, study their requirements for raw materials and capital equipment, promote the liberalization of trade in these products and develop facilities for the training of specialists. The peaceful character of the Agency's objectives is ensured by a complete system of security control.

The Eurochemic Company, the first joint undertaking of O.E.E.C., has been formed to build and operate a plant for the chemical treatment of irradiated fuel. It will be erected at the Nuclear Research Institute at Mol, Belgium. The plant will treat approximately 100 tons of natural or slightly enriched uranium per year. The authorized capital of the company, 20 million European Payments Union units of account, divided in 400 shares, is held by the Governments or Atomic Energy Authorities of twelve European countries.

United States and U.S.S.R. are, for the first time, collaborating in a study of the effects of radio-active fallout. Dr. Willard Libby, a member of the U.S.A.E.C., recently disclosed that the two countries were exchanging samples of each other's soil for analysis.

Rules to ensure the safety and health of the public during the handling of nuclear products are being formulated by the International Atomic Energy Agency. Mr. W. Sterling Cole, director-general, said the rules would cover the operation of reactors, the transport of fissionable material and the disposal of radioactive waste. He added that the Agency would probably be in a position to get down to its technical and scientific tasks by the middle of March.

U.S. Scientists have been collaborating in the Windscale investigation. A team of six reviewed the reactor safety factors involved early in December. Later in the month a group of ten U.S. scientists attended a previously arranged discussion on irradiation and oxidation damage to reactor graphite. The agenda was broadened to include the Windscale mishap. Off-site aspects of the incident, including public health problems, were jointly discussed by U.K.-U.S. officials in January.

United Kingdom

Allegations that certain members of the staff at Windscale felt aggrieved at some remarks in the White Paper on the accident involving No. 1 pile are to be investigated personally by Sir Donald Perrott. He offered to go to Windscale to hear any representations the staff there may wish to make concerning factual statements in the White Paper.

The Japanese nuclear purchasing mission which arrived in the U.K. in three separate groups during January is having discussions with each of the main consortia before placing an order for a Calder Hall-type of power station for Japan. As the Japanese are anxious to start site work in October it seems highly likely that an announcement of a contract will be made shortly.

The Central Electricity Authority, which was dissolved at midnight on December 31, when the new Electricity Council and the Central Electricity Generating Board took over, installed 1,788 MW of new generating plant last year.

Scheme to erect a £1 million magnesium-extraction plant for Magnesium Elektron, Ltd., at Hopton, near Wirksworth, Derby, has been shelved because of the credit squeeze.

Sir Ashley Clarke, British Ambassador in Italy (left), was greeted by Signor Pella, Italian Foreign Minister when they met in Rome on December 28 for the signing of a 10-year agreement on industrial applications of nuclear energy.

Berkeley nuclear power station celebrated its first anniversary on January 7, when work started on the second reactor pressure vessel. Unlike the first vessel which was begun outside the reactor area and then towed into position, the No. 2 shell will be built on the prepared foundation. Shortly, the emphasis at Berkeley will turn from civil engineering to mechanical engineering: the welding of both pressure vessels will be proceeding simultaneously and the heat exchangers will be coming out from the site factory.

Factory inspectors are attending short training courses at Harwell, so that they can acquire enough knowledge to be of use to them when they visit factories where radio isotopes are employed.

Argentine

Enriched uranium weighing 80 lb. and valued at $110,000 (approximately £37,000) arrived in Buenos Aires during December.

Czechoslovakia

Construction of the first nuclear power station in the country will begin later this year, according to the Czechoslovak news agency. The station—in the Vah valley of Slovakia—will generate 150 MW; it is expected to be in operation in 1960. Technical assistance will be supplied by the U.S.S.R. in part-exchange for uranium ore from Kachymov and other mines in Bohemia.

France

The Tecnetron—a device claimed to be a great improvement on the transistor—has been developed by a French engineer, M. Teszner, at the National Centre of Telecommunications study. The device essentially consists of a small pulley-shaped strip of uranium coated with indium.

A special study is being made of the U.S. offer of assistance in the construction of nuclear-powered ships and submarines. France has already started to build a nuclear submarine, which will be fuelled by natural uranium; the construction could be speeded if the vessel were powered with enriched uranium.

German Democratic Republic

First East German reactor, a Soviet-built 2 MW water-cooled model using enriched uranium went into operation at Dresden on December 16.

German Federal Republic

Second reactor to go critical in West Germany—a 50 kW water boiler built by Atomics International of U.S.A.—is located at Frankfurt University.

Construction of the first research reactor (FR2) completely designed and developed by German industry and engineers has now begun at Karlsruhe. Foundations have been laid and work has started on associated buildings. The 12 MW heavy-water reactor will be fuelled by natural uranium.

Interatom International Atomreaktorban G.m.b.H. has been formed by North American Aviation, Inc. (Atomics International) and Demag A.G. of Inisberg, Germany. Initially, A.I. will handle engineering and manufacturing while Interatom will manage any projects and sub-contracting in Germany. Demag A.G. has extensive manufacturing facilities for heavy industrial equipment.

Hungary

Research reactor supplied by the U.S.S.R. is in course of construction at Debrecen, South East Hungary.

Recoiling of the neutrino was recently photographed at the Nuclear Research Institute at Debrecen. Dr. Sandor Szalay, director of the Institute, said that the picture, requiring exceptionally high speed photography, was taken with the aid of a Wilson cloud chamber.

Indonesia

Finance for nuclear research is to be made available by the Government. Dr. Sutikno Slamet, Finance Minister, told Parliament on January 6. Indonesia already has an agreement with the Soviet Union for collaboration in the development of nuclear energy and the money will be used principally to pay for Soviet technical assistance and for training Indonesians in the U.S.S.R.

Italy

The agreement for nuclear co-operation signed in Rome on December 28 by Sir Ashley Clarke, British Ambassador and Signor Pella, Italian Foreign Minister, is the first really comprehensive nuclear pact made by the U.K. with another country. The agreement provides for a full exchange of unclassified information, A.E.A. assistance in supplying British research and power reactors, processing of fuel, A.E.A. technical assistance for the design, construction and operation of fuel manufacturing and processing facilities and, finally, training of Italian personnel.

Japan

Four Japanese companies announced on January 16 that they hope to complete a joint study of plans for a nuclear-powered 65,000-ton d.w.c. tanker within a year. A spokesman for one of the companies said that the propulsion unit would be a 25,000-h.p. pressurized water reactor.

Long-term programme for nuclear power calls for the installation of 7,000 MW, the Japanese A.E.C. announced in December. Initially it is intended to build a Calder Hall-type, from Britain, together with pressurized water, and water boiler reactors from the U.S. Domestic production will subsequently develop gradually.

First of a series of atomic power delegations left for the U.K. on January 3. Leading the advance party was Mr. Tamaki Ipponmatsu, vice-president, Atomic Power Generation Co. A second group left on January 7 whilst the final group, including the president of A.P.G., Daigoro Yasukawa, left on January 17.

A sudden 5% drop in pressure inside Japan's first nuclear reactor—a 50 kW water boiler, completed in August, 1957—was reported in December. A spokesman for the Atomic Research Institute said it was not known whether the pressure loss would prove serious.

Scholarship fund enabling Japanese students to study nuclear science at American universities has been established with the proceeds ($10,000) from the fifth International golf championship and Canada Cup matches held in Tokyo last year.

Mexico

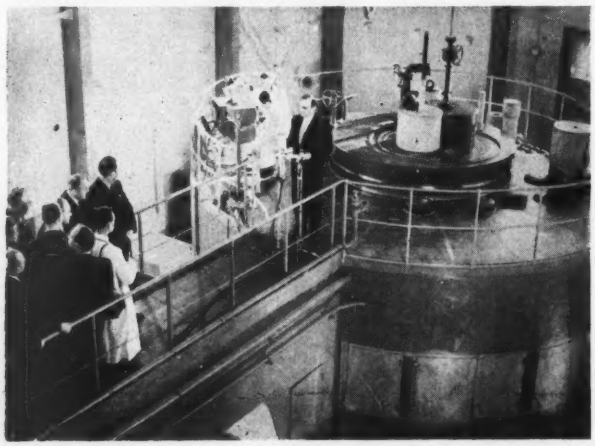
Mexican Light and Power Co. have been granted a credit of $11 million by the World Bank to enable the company to expand its generating capacity.

Netherlands

Negotiations with the U.S. for assistance in the construction of nuclear submarines were forecast by the Dutch Press early in January. Naval authorities, who declined to confirm the reports, commented that the U.S. made a general offer of technical assistance at the recent N.A.T.O. conference, but added that the study of nuclear propulsion for ships in the Netherlands was still in an early stage.

Newfoundland

Samples drilled at Kitts uranium mine in Labrador have produced an average of about 20 lb of uranium per ton of ore. Mr. J. R. Smallwood, Newfoundland premier, said that the mine might provide 200 tons of uranium a day when it goes into production.



East German physicist, Professor Barwich, spoke during the inauguration of the country's first reactor at Rossendorf near Dresden on December 16. The 2 MW pool-type reactor is similar to those supplied by the U.S.S.R. to other eastern-bloc countries.

Employees, engineers and scientists from Duquesne Light Co., Westinghouse Electric Corporation and the Atomic Energy Commission watched the nuclear-powered generating plant at Shippingport, Pa., come on load for the first time on December 18. Shippingport PWR became critical on December 2.

Norway

Hr. Gunnar Randers, director of the Institute of Nuclear Energy at Kjeller, and three colleagues recently returned from an eight-day tour of the Soviet Union. As guests of the Russian Academy of Science, the party was shown seven reactors, one of which was intended for the production of electric power on an experimental basis.

U.S.A.

EBWR—experimental boiling water reactor at the Argonne National Laboratory—has been successfully operated at a power of 50 MW (T), more than double its design level. The increase in the thermal output was achieved by making the water boil at a higher rate, resulting in faster circulation through the core and more rapid removal of heat.

HRE-2—homogeneous reactor experiment, No. 2, at Oak Ridge National Laboratory—achieved criticality on December 27. HRE-2 has a heat output of 5 MW. The two-region reactor consists of a core fitted with a heavy-water solution of uranyl sulphate surrounded by a blanket containing heavy water as its initial loading. The fuel solution is pumped under pressure through the reactor vessel where it is heated by uranium fission, then through heat exchangers where the heat produces steam. The reactor plant includes chemical processing equipment for purifying the irradiated fuel solution by continuously removing solid corrosion and fission products.

U.S. Army has authorized construction of its first nuclear power plant in the field. The reactor—an APPR similar to that developed at Fort Belvoir, Va.—will be built at Fort Greely, Alaska, 60 miles south of Fairbanks on the Alaska highway. The plant will be dual purpose, producing 42 million B.t.u./h of steam and about 1.7 MW of electricity. Congress has authorized $5,675,000 for the project.

Third nuclear submarine, *The Skate* was commissioned at Groton, Connecticut, on December 23.

Westinghouse Electric Corp., of Pittsburgh, have been awarded a contract to design and supply reactor components for the U.S. Navy's new nuclear-powered aircraft carrier. The contract, valued at $46,050,000, covers such items as controls, valves, pumps, instrumentation and so on. Westinghouse already had a contract to design and supply the pressure vessel and steam generators. The nuclear propulsion plant has been developed at the U.S.A.E.C. Bettis plant, in Pittsburgh, which is wholly Westinghouse operated. The carrier is being built by Newport News Shipbuilding and Drydock Co.

Vitro International, with headquarters in Geneva, Switzerland, has been formed by Vitro Corp. to handle the company's European sales including nuclear engineering components.

General E'ectric will not accept any more fixed-cost contracts for construction of nuclear power facilities, Mr. Ralph J. Cordiner, president, has announced. Future contracts will have escalator clauses to protect the company from costs which arise after the original estimates. Referring to the Dresden, Illinois, nuclear power station which General Electric is constructing for a group of utilities headed by Commonwealth Edison Co., Chicago, Mr. Cordiner commented that costs have exceeded the contract price of $45 million.

Contract for development of nuclear propulsion for aircraft awarded to United Aircraft Corp. in May, 1953, has just been extended to September 30, 1960. So far, the cost-plus-fixed-fee contract placed by U.S.A.E.C. has cost about $15 million annually. The work is being done at U.A.C.'s Pratt and Whitney division at Connecticut aircraft nuclear engine laboratory recently completed by the U.S. Air Force at Middletown, Conn.

Westinghouse Electric Corp. claim to have developed a new pump for use in high-temperature liquid metal-cooled reactors. The pump has already operated continuously for 3,500 hours at temperatures above 1,000° F. Highest temperature reached was 1,265° F.

Free services of up to 30 nuclear technicians will be made available by the U.S. to under-developed countries, Mr. Robert McKinney has told a meeting of the Board of Governors of the International Atomic Energy Agency. The U.S. will also award scholarships to 120 students nominated by the Agency, and contribute $250,000 (approx. £89,000) to the Agency's scholarship fund on the assumption that other members will supply the balance.

A.E.C. Headquarters are now located in the new building at Germantown, Maryland.

Argonne National Laboratory has been authorized to build a 12.5 GeV accelerator.

Curtiss-Wright, proceeding with a programme of diversification in industry, have developed and built a general-purpose research reactor which the company propose to market.

A.E.C. Licences and Permits. To General Electric for export of a 3 MW (T) open pool reactor to Caracas, Venezuela: value $584,000. To A.C.F. Industries for export of a 20 MW (T) tank-type water cooled and moderated reactor using 90% enriched uranium to Reactor Centrum Nederland, Petten, Netherlands: value $1,850,000. To the National Advisory Committee for Aeronautics for construction of a low power (1/10 W) homogeneous reactor using uranyl fluoride-water solutions at Lewis Flight Propulsion Laboratory.

To the Nuclear Materials and Equipment Corporation the first licence to enable a private company to produce enriched uranium metal for commercial use.

U.S.S.R.

First nuclear reactor in the Ukraine is now being built for research work at the Ukrainian Academy of Sciences.

Soviet Union has offered to grant full scholarships at higher educational establishments to 25 students from under-developed countries. The offer was made in a letter to Mr. W. Sterling Cole, director-general, International Atomic Energy Agency. In addition the Soviet will provide facilities for 15 to 20 students on scholarships purchased from Agency funds.

Yugoslavia

A new research reactor will become critical next September at an Institute near Belgrade, Parliament was told in December. Mr. Avdo Humo, finance secretary, said the reactor was included in a nuclear energy programme costing about £6 million in 1958. The reactor has been purchased from the U.S.S.R.

Several hundred deposits of uranium have been discovered in Yugoslavia. Announcing this, Mr. Aleksander Rankovic, vice-president, said that exploitation of the ore would be speeded up. Because Yugoslavia had abundant hydro-electric sources, she was more interested in nuclear ship propulsion than nuclear power stations.

Orbits in Industry

ANYONE finding himself amongst technical types can always while away the odd half-hour by asking one simple question, which can usually be relied upon to start an argument occasionally reaching the proportions of a "cag" (officially defined as "a naval argument carried out in three stages; direct assertion; flat contradiction; personal abuse"). The question is merely: "What is the difference between a tube and a pipe?" and the answers will be legion. Some will maintain that it is a question of dimensions, some will assert that a tube is merely a piece of metal wrapped round a hole and that a tube becomes a pipe when it is used for conducting something from one place to another.

This all arose, of course, out of something entirely different; the consideration, in fact, of the difference between tubes as seen from different viewpoints. In the nuclear field we regard tubes as holes surrounded by an impermeable (we hope) barrier, and it was interesting to be reminded at the showing of "Tubular Engineering," a new film produced for Tubewrights, Ltd., by Ace Distributors, that the structural engineer regards a tube as a circular structural member which has had the relatively inefficient inside bits scooped out, leaving it very much lighter and nearly as strong, so that it can do peculiar things, such as a self-supporting radio mast 603 ft high, and roof trusses of 218 ft span. Although it is some 10 years since tubular engineering really got going with the world's biggest dragline unit that Tubewrights built in conjunction with Ransomes and Rapier, for Corby, many of us still do not realize what can be done with tubes—although the strength-weight ratio of the common bicycle should remind us.

Incidentally, while we are considering tubes, another problem in definition arises. The fantastic piece of tube that Accles and Pollock attached to their Christmas card, that made a hypodermic needle look like a stick of macaroni, was officially scheduled as having a bore of 1 thou., and an overall diameter of 6 thou. Since this means that the ratio of O.D.-I.D. is 6-1 is it classed as thick-walled tube?

How Much Research?

The proportion of a manufacturer's effort that should be devoted to research is a question that evolves nearly as much argument as the pipe and tube controversy, and varies so widely between different industries, and between individual companies in the same industry, that it is impossible to lay down any standards. On a recent visit to the research laboratories of William Jessop and Sons Ltd., it was rather surprising to find that the complement was some 6% of the total strength of the company. Maybe it is this progressive attitude which has kept them in the top flight of the steel industry since 1774—when they practically comprised the steel industry. If we were in frivolous mood (and we usually are) the attitude might be summed up as: "Research, and you lead the van: neglect research, and you're in the cart."

Another thought triggered off by the Jessop visit concerned vacuum melting, the techniques of which were dealt with fairly fully in this journal for August, 1956. While in one way this is the answer to a metallurgist's prayer, like all forms of progress, it brings its own problems with it. Since impurities can be reduced to parts per million instead of percentages, it becomes necessary to work in ppm and, when one considers that 10 ppm of boron will double the life of a heat resisting steel, alloying techniques take yet another step forward from the early days of chucking in a handful of something and hoping for the best. Also, the materials that usually appear in an analysis with the brief notation "trace" become increasingly important. If any more headaches are required, think of the elements like antimony and lead that are volatilized right out of the melt. On a ppm basis can they be forgotten?

Boys for the Jobs

The February, 1957, instalment of these not-so-profound thoughts dealt with the Schoolboy's Own Exhibition and its accent on careers. Although this year's exhibition laid just as much emphasis on careers, either directly or indirectly (the Electrical Development Association was holding a quiz programme with cash prizes to pin-point promising youngsters) it is regrettable to report that the nuclear energy industry was hardly represented at all. The U.K.A.E.A. was not among those present and the only bit of nuclear publicity that Tangent saw was a picture of Berkeley power station on the MetroVick stand. Doubtless the A.E.A. had the best of reasons for not exhibiting—they probably feel they're in too many exhibitions as it is—but the fact remains that nuclear engineering is badly overshadowed in the juvenile world by guided missiles, Sputniks, and all the rest of the grown-ups' fireworks, and cannot even compete with the old-fashioned aeroplane so far as the younger generation is concerned.

Pop Parade

What seemed to be final and convincing proof that atomic matters are very far from being Top of the Pops is the absence of any representation on cigarette cards. The London Cigarette Card Co., which had a stand surrounded by a milling mob, issues a catalogue listing over 2,000 series and had on sale varieties, ranging from bathing belles of the Mack Sennett period to space travel; yet even the "Modern Wonders" series did not contain a single reference to the atom.

> Imperious Cæsar, dead and turned to clay,
> Might stop a chink, to keep the wind away;
> It's hard that public interest should flag,
> Till Calder won't make stuffing for a fag.

This state of affairs must not be allowed to continue. We must be Grand Old Troupers, and stage a come-back for next year. Up, Guards, and Atom!

"Heigh-Ho! Said Rowley . . ."

The frogman who demonstrated operations in the active area of the new experimental cell at Harwell aroused many questions at a recent Press visit. "How is his air hose paid out? . . .How did he keep cool? . . . What happened if the air supply failed? . . . What happened if he tore his suit? . . .", all of which received prompt and informative answers. Tangent's own question, "What happens when his nose itches?" was considered frivolous and unnecessary. Yet it can be a very real problem, and Tangent speaks from personal experience—not in the fields of insidious alpha contamination, it is true—but in being lowered into the peculiar concoction of indian ink and assorted vegetables that passes for sea-water in the estuarine approaches to these islands, clad in one of Siebe Gorman's gents suitings. The instant that the glass facepiece is screwed home and the traditional slap on the copper bowler warns one that now is the time to step off the ladder, the problem of nose-inaccessibility becomes acute, quite overshadowing such mundane matters as depth-keeping, not losing one's shot-rope or kinking the air hose. Since diving helmets and the Harwell frogman's rig are both designed to give adequate clearance for the face, rubbing the nose against a portion of it would only be possible to the legendary Cyrano de Bergerac or the almost-legendary Mr. Durante. That being so, could not Mr. Siebe, Mr. Gorman (or even one of the Co. Ltd.) devise some built-in form of scratcher? A windscreen wiper is the first idea that leaps to mind, but this, it is felt, would be too agonisingly slow and regular, and probably lead to dislocation of the neck trying to follow the blade movement to increase the "time of dwell." A preferred design would be a rotary scratch-brush, driven by a small air turbine, that would move into position and retract at regular intervals, like a grinding attachment on an automatic machine. The retracting mechanism, must, however, be absolutely reliable. It must never be said that the U.K.A.E.A. are holding their employees' noses to the grindstone.

Tangent

Personal

Mr. L. Rotherham.

Dr. H. W. Melville.

Dr. Allen-Williams.

Appointments

Mr. Leonard Rotherham, director of research and development at Industrial Group Headquarters, Risley, becomes a full-time member of the Central Electricity Generating Board on April 1. He is succeeded by **Dr. H. Kronberger,** O.B.E.

Lord Citrine has been nominated as a part-time member of U.K.A.E.A. in succession to **Sir Luke Fawcett,** the appointment being for a three-year period. Until December 31 last year Lord Citrine was chairman of the Central Electricity Board.

Four deputy directors-general have been nominated to the International Atomic Energy Agency: **M. Paul R. Jolles,** Switzerland (Administration); **Mr. V. V. Migulin,** professor of physics, Moscow University (Formation of the Agency and Documentation); **M. Hubert de Laboulaye,** technical consultant, French A.E.C. (Technical Department), and **Dr. Henry Seligman,** head, Isotopes Division, A.E.R.E., Harwell (Research and Isotopes).

Mr. Francois de Rose, of France, as president of C.E.R.N., the European Organisation for Nuclear Research, for 1958. **Mr. J. Willems,** of Belgium, and **Prof. W. Heisenberg,** of Germany, as vice-presidents; **Prof. E. Amaldi,** of Italy, as chairman of the scientific policy committee, and **Mr. J. H. Banner,** of the Netherlands, as chairman of the finance committee. **Dr. H. M. Melville,** F.R.S., secretary of the U.K. Department of Scientific and Industrial Research, succeeds **Sir Ben Lockspeiser** as a U.K. delegate to C.E.R.N.

Mr. F. Waine, J.P., director, British Insulated Callender's Cables Ltd., and **Mr. S. Geipel,** chairman, William Geipel Ltd., as president and vice-president of the newly formed Electric Cable Makers Federation.

NEW YEAR HONOURS

KNIGHTS

Mr. William Richard Joseph Cook, deputy director, A.W.R.E., Aldermaston.

Mr. Ashley Skelton Ward, president, Thos. W. Ward, Ltd.

Mr. Walter John Worboys, director, Imperial Chemical Industries, Ltd.

K.C.B.

Dr. Harry W. Melville, secretary, Department of Scientific and Industrial Research.

G.B.E.

Sir Harold Edgar Yarrow, chairman and managing director, Yarrow and Co., Ltd.

K.B.E.

Brigadier George Hands Walton, director, Morgan Crucible Co., Ltd.

C.B.E.

Mr. Eric Harold Ball, managing director, British Thomson-Houston Co., Ltd.

Alderman Sir (William) Hugh Stobart Chance, deputy chairman, Chance Bros., Ltd.

Mr. James Alfred Mason, director, Automatic Telephone and Electric Co., Ltd.

Mr. Clifford Metcalfe, managing director, E.M.I. Electronics, Ltd.

O.B.E.

Mr. David Gardner Brown, managing director, Redheugh Iron and Steel Co. (1936), Ltd.

Mr. Reginald Artane McMahon, secretary, British Electrical and Allied Industries Research Association.

M.B.E.

Mr. Geoffrey Hollingsworth, assistant manager, steel production, Arthur Balfour and Co., Ltd.

The Central Electricity Generating Board announces the following appointments: **Mr. D. P. Sayers,** B.Sc., M.I.Mech.E., M.I.E.E., M.Amer.I.E.E., as chief commercial and operations engineer; **Mr. E. S. Booth,** M.I.Mech.E., M.I.E.E., as chief design and construction engineer; **Mr. J. L. Ashworth,** A.M.I.Mech.E., A.M.I.E.E., as deputy regional director, North West, Merseyside and North Wales Region; and **Mr. B. C. Pyle,** M.I.E.E., as chief assistant project engineer to the Northern Project Office. Five new divisional controllers have also been appointed: **Mr. W. H. Dunkley,** B.Sc., M.I.Mech.E., M.I.E.E. (South Eastern); **Mr. A. R. Clague,** M.Eng., A.M.I.Mech.E. (South Western); **Mr. F. W. Skelcher,** M.I.Mech.E., M.I.E.E. (Midlands); **Mr. W. Wilde,** B.Sc. (Eng.), A.M.I.Mech.E., A.M.I.E.E., M.Inst.F. (South Wales); **Mr. C. G. Richards,** M.Sc. (Tech), (Yorkshire).

Dr. D. J. F. Allen-Williams, of Davey Paxman and Co., Ltd., is leaving to take up the chair of Mechanical Engineer at the University of West Australia in a few weeks' time.

Mr. A. R. Mathias as chairman of the Lead Development Association for the current year, succeeding **Mr. H. L. Evans,** who had held this office since January, 1956. **Lt.-Col. W. E. Grey** re-appointed chairman of the lead sheet and pipe section of the Association.

The Rt. Hon. Antony Head, C.B.E., M.C., M.P., as a director of Associated Electrical Industries, Ltd.

Mr. A. H. Hird, A.C.G.I., B.Sc., M.I.Mech.E., a special director of Vickers, as a member of the board.

Mr. R. J. W. Rudkin, B.Sc., M.I.N.A., as general manager, naval yard, Vickers Armstrongs (Shipbuilders) Ltd.

Mr. K. T. O. Cox as senior planning officer with the research and development branch of U.K.A.E.A.

Mr. F. J. Lane, O.B.E., M.Sc., M.I.E.E., previously deputy chief engineer (transmission) C.E.A., has left to take up a senior position with Preece, Cardew and Rider, the consulting engineers.

Mr. G. M. Ettinger, M.Sc., as engineer-in-charge of a new engineering research group at Marconi Instruments Ltd. The group will have a section dealing with nucleonic instrument design.

Mr. F. Waine.

Mr. G. M. Ettinger.

Dr. H. Kronberger.

A.V.M. Spencer.

Mr. E. G. Bell.

Mr. W. J. Lloyd.

Mr. R. Y. Parry.

Dr. R. S. Silver.

Air Vice-Marshal G. M. C. Spencer, C.B., C.B.E., has joined the technical liaison staff of William Jessop and Sons Ltd.

Mr. Ernest G. Bell, A.M.I.E.E., as sales manager (instruments), Servomex Controls Ltd.

Mr. W. J. Lloyd, B.Sc., A.M.I.E.E., as general manager of Short and Mason Ltd.

Mr. R. J. Kingsnorth, M.I.E.E., A.M.I.Mech.E., as manager of the process control division of Elliott Bros. (London) Ltd., a member of the Elliott-Automation Group.

Dr. R. S. Silver as general manager, technical division, G. and J. Weir Ltd.

Following the resignation of **Mr. V. Thomas, Mr. G. Ensor,** general manager of Fielden Electronics, Ltd., has resumed the office of sales manager in addition to his other duties. **Mr. E. Pearson** becomes assistant sales manager.

Mr. H. Desmond Carter as chairman of Crossley Brothers, Ltd. (in addition to holding the office of managing director), in succession to the late **Sir Kenneth I. Crossley,** who died on November 22, 1957.

Mr. F. C. Wright succeeds **Sir Thomas Spencer** as managing director of Standard Telephones and Cables Ltd. Sir Thomas remains as chairman of the company and its subsidiaries.

Dr. W. D. Scott, F.R.I.C., B.Sc., A.R.C.S., as assistant managing director of B.T.R. Industries, Ltd.

Mr. R. Sosbe as representative for James Gordon and Co. Ltd., in Lancashire, Cheshire and North Wales.

Mr. W. F. B. Baker, D.F.H., A.M.I.E.E., as director, P. H. Jackson and Co. Ltd.

Mr. A. O. Ahlquist, M.A., A.M.I.Mech.E., as sales manager, mechanical department, Metropolitan Vickers Electrical Co., Ltd. He succeeds **Mr. H. Lawson-Jones,** who will act in an advisory capacity after his transfer to Metvick's sales management.

Mr. Ernest G. Lennard, M.I.Ex., as managing director of the Penco Export Co. Ltd., a new subsidiary of the Pena Group.

Mr. R. Y. Parry as technical manager of Isotope Developments, Ltd.

Mr. T. E. Potts as a managing director of the British Oxygen Co., Ltd.

Mr. S. J. Bellamy as general manager of Peter Brotherhood, Ltd., on the retirement of **Mr. A. Marcus Neal.** Mr. Neal remains chairman of the company.

Mr. Gwilym A. Price, chairman and president, Westinghouse Electric Corp., as chairman of the Board; **Mr. Mark W. Cresap, Jnr.,** as president and chief administrative and operating officer, and **Mr. E. V. Huggins** as chairman of the executive committee of the Board and vice-president.

Mr. J. A. C. Williams, M.Sc., A.M.I.Mech.E., A.F.R.Ae.S., A.B.Ps.S., as principal of the College of Aeronautical and Automobile Engineering, Chelsea.

RETIREMENTS

Mr. John Lloyd, chief labour officer, A.E.A., has retired.

Mr. H. C. Baigent has retired from the Board of A.P.V. Co., Ltd.

TOURS

Professor R. V. Jones, of Aberdeen University, is currently visiting Washington to discuss with U.S. scientists the production of lead fluoride crystals which have been developed at the University.

Mr. J. E. C. Bailey, C.B.E., chairman and managing director of Baird and Tatlock (London) Ltd. and Hopkin and Williams Ltd., left the United Kingdom on January 18 to visit the companies' branches, agents and representatives in Rhodesia, South Africa, Australia, New Zealand, Singapore and Ceylon.

Industrial Notes

The English Electric Co., Ltd., have received an order for rectifier equipment valued at approximately £1¼ million for the Nangal fertilizer/heavy water project in India. The rectifiers will be used principally to supply d.c. power to electrolytic cells for the production of hydrogen.

British Petroleum, Ltd., have ordered a 4 MeV linear accelerator for their research station at Sunbury-on-Thames, Middlesex. Design and construction of the accelerator and its associated equipment are being undertaken by Mullard Research Laboratories on behalf of Philips Electrical, Ltd.

Arrangements are being made for the participation of British companies in the 5th International Congress of Electronics and Atomic Energy which takes place in Rome from June 16 to 30, 1958. Details can be obtained from Auger and Turner Group, Ltd., 40 Gerrard Street, London, W.1.

Constructors John Brown Ltd. have recently established a research and development station at Leatherhead, Surrey. The primary object of the station is to undertake sponsored development work on behalf of government departments and industrial organizations, and also for the engineering and construction divisions of C.J.B. It covers the following fields: Process development and investigation of chemical engineering problems; development of automatic control systems and their application; and special problems of nuclear engineering.

The Yorkshire Copper Works Ltd. is, on January 27, submitting proposals to shareholders for a merger of the company with Imperial Chemical Industries Ltd.

Rio Tinto-Dow Ltd. has been formed by The Rio Tinto Mining Co. of Canada Ltd. and Dow Chemical of Canada Ltd. to produce thorium and rare earths.

Nuclear Enterprises (G.B.), Ltd., of Bankhead Medway, Sighthill, Edinburgh, have obtained a contract for the production of the first multi-channel industrial tracer scintillation spectrometer to be made in Europe. The contract was placed by the Ekono organization of Helsinki, Finland, and the equipment will be used for investigations into cellulose, pulp, paper and other plants. Nuclear Enterprises have also been appointed exclusive concessionaires in Great Britain for sodium iodide and other scintillation crystals made by the Harshaw Chemical Co. of Cleveland, Ohio.

Processes and Equipment

Dry Cooling Towers

A cooling system enabling power stations to be sited in areas where large volumes of cooling water are not available, is being developed by English Electric. The company is negotiating with the Central Electricity Generating Board for the design and construction of a commercial scale installation. The "dry cooling tower" plant uses a system proposed by two Hungarian engineers, Prof. L. Heller of Budapest University, and Mr. L. Forgö.

Up to the present, the only practical method of condensing the steam in large plants has been by passing large volumes of cooling water through surface condensers, which has normally restricted siting of power stations to rivers, lakes and coasts. The essential features of the new scheme are the injection of pure water into the steam and the cooling of the mixture of water and condensate by air in large heat exchangers, or coolers, of special design fitted round the base of the dry cooling tower. In the new system the initial supply of water is used again and again, with only comparatively slight losses to be made up.

As the system is completely closed the water in circulation will be of condensate purity, and the plant will, therefore, be free from internal corrosion troubles. The flow of air through the cooler is produced by either induced draught fans or natural draught, the choice depending on such factors as fuel cost, atmospheric temperature and size of unit.

Two factors contribute to the overall economy of the scheme. First, the cooler, which is made entirely of aluminium and is simple, effective and cheap to construct; secondly, the incorporation of the spray condenser, which eliminates the drop in temperature between the condensate and cooling water that occurs in the conventional condenser.

(The English Electric Co., Ltd., Marconi House, Strand, London, W.C.2.)

Temperature Control

The Foster resistance thermometer controller, Model 3510, has been developed as a low-cost, accurate and durable fully electronic temperature controller for use in association with special Foster fast response thermometer elements, which provide a degree of control not normally obtained with standard elements. Temperature ranges cover from −50°C up to +350°C and the 15-in.-long scale is overprinted with the equivalent Fahrenheit range. All resistances comprising the Wheatstone Bridge system are accurately calibrated and aged so that control point drift is entirely eliminated.

The control operates on a differential of 0.1°C but can be detuned to operate on wider differentials (up to 5°C if required) by a simple adjustment of the sensitivity control. Variations in mains voltage within very wide limits make no difference to the accuracy of the instrument.

(Foster Instrument Co., Ltd., Letchworth, Herts.)

Operation Recorders

The Autovisor, recently introduced by F. C. Robinson and Partners, provides an automatic and continuous record on one chart, of the periods of operation of from one to ten different machines or processes. The recording is made by an electrically-operated pen marking a chart which moves at a speed applicable to the process or machine being monitored. A feature of this instrument is that the recording, which is clearly identifiable, is made without the use of ink or any marking fluid.

The marking of the chart can be initiated by any device which will close a set of contacts—for example—a simple relay across the machine's motor; a microswitch; a pressure switch; a flow switch, etc., whichever device is suitable for the particular application. In addition to recording the frequency of an operation, the Autovisor will record its duration and by incorporating a solenoid operated counter, the total production figure. Various types of Autovisor Operations Recorders are available: they include single pen models, both strip and disc, and ten pen models, giving either vertical or horizontal display.

(F. C. Robinson and Partners, Ltd., Councillor Lane, Cheadle, Cheshire.)

Industrial X-ray Service

The radiological inspection service operated by the X-ray division of Palmer Aero Products has been considerably extended as a result of expansion and re-equipment of their test house at Penfold Street, London, N.W.8. New radiographic equipment of the latest design will enable the company to deal quickly and efficiently with a wider range of work, whilst specially designed handling and setting equipment will facilitate the throughput. The new test house, which makes available X-rays (3 in. maximum steel penetration), gamma rays, and magnetic and fluorescent crack detecting processes, will cater for the inspection of all types of castings and weldments up to one ton.

(Palmer Aero Products, Ltd., Herga House, Vincent Square, London, S.W.1.)

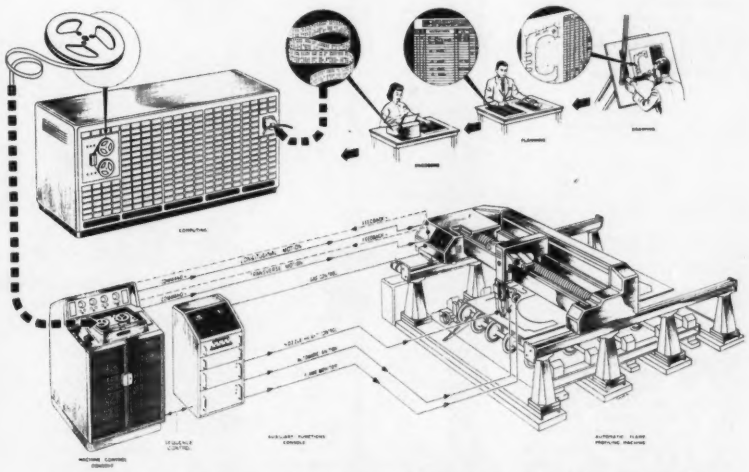
Computer-controlled Flame Cutting

In conjunction with the computer division of Ferranti, Ltd., British Oxygen Gases, Ltd., of Spencer House, London, S.W.1, have developed a method of controlling oxy-acetylene plate cutting that eliminates the need for templates or optical marking out. The general scheme is shown in simplified form in the accompanying diagram. Dimensions on the drawing are given in co-ordinate form, based on a datum line outside the profile to be cut. From this, a planning sheet is prepared giving dimensional co-ordinates, kerf widths and cutting speeds. These data are encoded on punched tape, which is then fed to a computer unit. This operation is carried out on a teleprinter unit using punched tape with a conventional 5-unit code, and the operation is simply one of copy-typing.

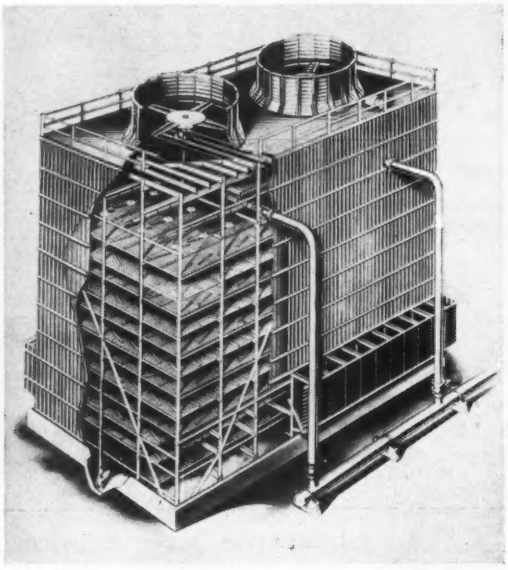
In the computer, the path of the cutter between the change points marked on the punched tape is evaluated, and recorded on a magnetic tape in the form of pulses. The magnetic tape is then placed on the control console of the flame-cutting machine and controls servo-motors locating the flame-cutting head on the XY axes. The machine automatically cuts out the original design.

Continuous nozzle height sensing is incorporated, together with automatic ignition and flame monitoring equipment. It is not necessary for a company to own a computer unit, since a 24-hour centralized service is envisaged for preparation of magnetic tapes from the punched tape.

(British Oxygen Gases Ltd., Spencer House, London, S.W.1.)



Schematic diagram showing the equipment layout for the British Oxygen-Ferranti computer-controlled flame-cutting system.



(Left) The latest design of Counterflo induced draught cooling tower by Head Wrightson Processes embodies several improved features for water and air distribution.

Induced Draught Tower

Head Wrightson Processes Ltd. announce that work has been completed on a new design of their Counterflo induced draught cooling tower. This type of tower is widely used in the United States: Head Wrightson offer this equipment in the United Kingdom and British Commonwealth under licence from Fluor Products Company of Los Angeles.

Continuous research into improved methods of industrial cooling has produced some novel design features for the water and air distribution in this new design of tower. The Counterflo induced-draught cooling tower can be composed of one or a number of cells each equipped with an induction fan which draws the air through the tower from louvre intakes. Water is distributed down the tower from a novel all-timber but totally enclosed distribution system through splash-type grid decks, thus providing a counterflow action.

The tower is constructed of prefabricated timber or concrete units and these factory-made components can be erected on site by unskilled labour teams. A new feature is the inclusion of asbestos panels as sheathing for towers in certain circumstances.

(Head Wrightson Processes Ltd., 24/26 Baltic Street, London, E.C.1.)

Metallic Borides

A comprehensive range of metallic borides is now available in the U.K. Borax Consolidated Ltd., can supply two series of borides, one of high chemical purity (not less than 99.8%) and the other comprising technical grades of minimum purity of the order of 99%.

Several borides of the more important metals such as chromium, molybdenum and tungsten appear either in one or both of the ranges as well as the borides of some of the less common metals such as titanium, zirconium, vanadium, niobium and tantalum. The high melting points of metallic borides (up to 3,100°C), and their hardness, make them compounds of major metallurgical interest. Their corrosion resistance, both to noxious gases and to liquid or gaseous metals, has stimulated research into the possibilities of their use in gas turbines and other locations where their inert character is of importance. Many research organizations are investigating fabrication techniques, both from the point of view of pressing by powder metallurgy techniques and of forming coatings on metals or alloys. The part they play in cermets—the new series of metal-ceramic compounds—is well known, and they may also be of use in tools and dies. The eleven compounds in the pure series are dense, hard powders of average particle size of 10-50 microns, and the fourteen in the technical series are finer, averaging 5-10 microns in particle size.

Two technical data sheets—one for each series—have been published by Borax Consolidated. These list the chemical analysis, specific gravity, melting point and hardness of each compound. The electrical conductivities, which are of some importance in certain applications, are also included.

(Borax Consolidated, Ltd., Borax House, Carlisle Place, London, S.W.1.)

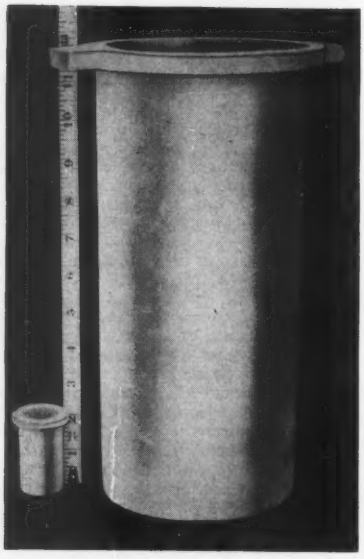
Briefly . . .

British Insulated Callenders Cables, Ltd. have introduced a 33kV ductless, shaped-conductor, oil-filled three-core cable (D.S.O. cable) for underground transmission.

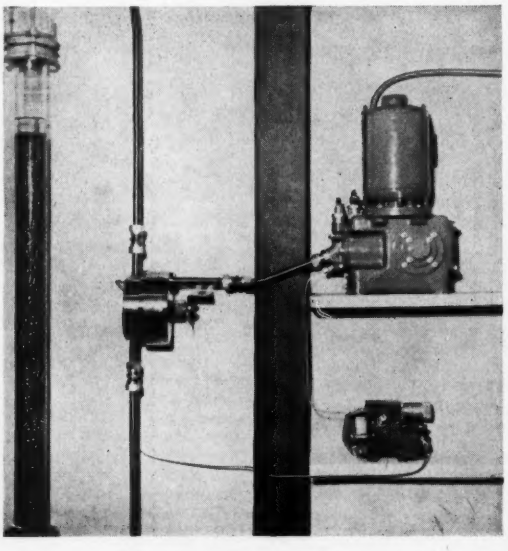
Chloride Batteries, Ltd., Exide Works, Swinton, Manchester, have supplied 14 Keepalite emergency lighting sets to Dounreay establishment. Each set comprises 6 chloride sealed-in cells of 40 Ah capacity.

Venner Electronics Ltd., Kingston By-pass, New Malden, Surrey, are marketing a transistorised millisecond stopclock for time measurement in the range from 0.1 ms to 27.8 hrs.

Labgear Ltd., Willow Place, Cambridge, have produced a non-destructive flash tester for the voltage range 250 to 2,000. Breakdown of insulation is indicated on a moving-coil meter.



(Left) Moulded porous cylindrical filter cups in Teflon. The larger element is 12 in. high, 5½ in. o.d. and 5 in. i.d. The smaller unit is 2½ in. high, 1½ in. o.d. and 1 in. i.d. (Porous Plastic Filter Co. Inc., 30 Sea Cliff Avenue, New York).



(Right) Remotely-operated metering equipment developed in conjunction with A.E.R.E., Harwell, by Kontak Ltd., of Grantham. For use with corrosive and radioactive media, the metering range is 750 mls. per minute (9 g.p.h.). Suction lift up to 12 ft. w.g. Delivery pressure up to 100 ft. w.g.

BUYER'S GUIDE ADDENDA

Address Section

Bastian and Allen Ltd., Ferndale Terrace, Harrow, Middlesex. Tel.: Harrow 7171. T.A.: Pyrogenic, Harrow.

Broads Manufacturing Co. Ltd., 4 South Wharf, Paddington. London, W.2. Tel.: Paddington 7061.

Bronx Engineering Co. Ltd., Lye, Worcs. Tel.: Lye 2307, 2308. T.A.: Bronx, Lye.

Conveyancer Fork Trucks Ltd., Warrington, Lancs. Tel.: Warrington 35241. T.A.: Hydraulics Warrington.

Cravens Ltd., Staniforth Road, Darnall, Sheffield, Yorks. Tel.: Sheffield 41391. T.A.: Craven Sheffield 9.

Cutrock Engineering Co. Ltd., Dollis Park, London, N.W.3. Tel.: Finchley 5978.

Designs and Installations, 28-30 Great Peter Street, London, S.W.1. Tel.: Abbey 5809.

English Asbestos (Sales) Ltd., Orchard Works, Bath Road, Bristol, 4. Tel.: Bristol 75321.

E.R.S. Ltd., Brookwood Road, London, S.W.18. Putney 3402.

Gloster Aircraft Co. Ltd., Technical Developments Division, Gloucester. Tel.: Gloucester 67011. Telex: 43-143. T.A.: Glosaircra, Gloucester.

Hawker Siddeley-John Brown Nuclear Construction Ltd., 8 The Sanctuary, Westminster, London, S.W.1. Tel.: Abbey 7151.

Hedin Ltd., Commerce Estate, South Woodford, London, E.18. Tel.: Buckhurst 6601/2.

I.T.D. Ltd., 95-99 Ladbroke Grove, London, W.11. Tel.: Park 8070. Cables: Indusdev Nottarch London.

E. E. Jeavons and Co. Ltd., Tipton, Staffs. Tel.: Tipton 2161. T.A.: "Pipelines" Tipton.

Lee Guinness Ltd., Newtownards, Northern Ireland.

Mirrlees Watson Co. Ltd., The, Scotland St., Glasgow, C.5. Tel.: South 2701, 2704. T.A.: Mirrlees, Glasgow.

North West Machine Design Co. Ltd., 177 Kenton Road, Kenton, Harrow, Middx. Tel.: Wordsworth 0301.

Ransome and Marles Bearing Co. Ltd., Newark-on-Trent. Tel.: Newark 456. Telex: 37-306.

Saunders-Roe (Anglesey) Ltd., Beaumaris, Anglesey. Tel.: Beaumaris 130 (six lines). T.A.: Searoads, Beaumaris.

Singer Instrument Co. Ltd., 83 London Street, Reading, Berks.

John A. Smith Ltd., 24 Lichfield Street, Wolverhampton. Tel.: Wolverhampton 24826.

Edward Wood and Co. Ltd., Ocean Ironworks, Trafford Park, Manchester, 17. Tel.: Trafford Park 2341.

Classified Section

BOILERS—ELECTRODE STEAM
Bastian and Allen Ltd., Harrow.

COUNTERS—PROPORTIONAL
Nuclear Enterprises (G.B.) Ltd., Edinburgh.

CONTROL ROD MECHANISMS
Designs and Installations, London.
Lee Guinness Ltd., N. Ireland.

COOLING TOWERS
English Electric Co. Ltd., London.

CUTTING MACHINES
Cutrock Engineering Co. Ltd., London.

DRY BOXES
Saunders-Roe (Anglesey) Ltd., Anglesey.

E.H.T. UNITS
Nuclear Enterprises (G.B.) Ltd., Edinburgh.

INDICATORS AND CONTROLLERS
Gloster Aircraft Co. Ltd., Gloucester.

INSTRUMENT PANELS
Constructors - John Brown Ltd., London.

PIPE FABRICATIONS
Cravens Ltd., Darnall, Sheffield.
Hilmor Ltd., London.
E. E. Jeavons and Co. Ltd., Tipton.

REMOTE HANDLING EQUIPMENT —MANIPULATORS
Singer Instrument Co. Ltd., Reading.

SIMULATORS—REACTOR
English Electric Co. Ltd., London.

SPECTROMETERS
Nuclear Enterprises (G.B.) Ltd., Edinburgh.

SURFACE HEATERS—ELECTRIC
Electrothermal Engineering Co. Ltd., London.
Hedin Ltd., London.

TURBINES—STEAM
The Mirrlees Watson Co. Ltd., Glasgow.

Meetings to Note

JANUARY

January 30.—"The Chemical Processing of Nuclear Fuels" by B. F. Warner. Institution of Chemical Engineers, Graduates and Students Section, East Midlands Centre, Saracen's Head Hotel, Derby Road, Loughborough.

FEBRUARY

February 4.—"Temperature Transients in Gas-cooled Thermal Nuclear Reactors" by J. H. Bowen, B.Sc.(Eng.), and E. F. O. Masters, B.Sc. "Boron-Trifluoride Proportional Counters" and "The Design, Performance and Use of Fission Counters" by W. Abson, B.Sc., P. G. Salmon and S. Pyrah. "The Application of Digital Computers to Nuclear Reactor Design" by J. Howlett, B.Sc., Ph.D. British Nuclear Energy Conference, Institution of Electrical Engineers, 2 Savoy Place, London, W.C.2, at 5.30 p.m.

February 4.—"Some Structural Aspects of Nuclear Reactors" by W. H. Chilton, A.M.I.Struct.E. Institution of Structural Engineers, Northern Counties Branch. Cleveland Scientific and Technical Institution, Middlesbrough, at 6.30 p.m. (Paper repeated on following evening at Neville Hall, Newcastle.)

February 18.—"Industrial Uses of CO_2" by T. B. Philip and R. Hamilton-Peters. Society of Chemical Industry, 14 Belgrave Square, London, S.W.1, at 5.30 p.m.

February 19.—"Nuclear Engineering: Some Difficulties in the First Ten Years" by Sir Christopher Hinton, K.B.E., F.R.S., F.Inst.F. Institution of Civil Engineers, Great George Street, London, S.W.1, at 5.30 p.m.

February 23.—"Ion Exchange as a Unit Operation" by R. Kressman. Institution of Chemical Engineers, North Western Branch, Birkenhead Technical College, at 7 p.m.

February 25.—"Prestressed-concrete Cylindrical Tanks" by L. R. Creasy. Institution of Civil Engineers, Great George Street, Westminster, London, S.W.1, at 5.30 p.m.

February 28.—"Nuclear Power and the Production Engineer" by I. Munro, B.Sc. Institution of Production Engineers, Derby Section, The College of Art, Derby, at 7 p.m.

MARCH

March 3.—"Advanced Types of Power Reactors" by J. V. Dunworth, C.B.E., M.A., Ph.D. Institution of Electrical Engineers, Mersey and N. Wales Centre, Royal Institution, Colquitt Street, Liverpool, at 6.30 p.m.

APRIL

April 10-11.—Conference on Nuclear Energy, at Eastbourne. Organized by the Federation of British Industries (21 Tothill Street, London, S.W.1). On the following day there will be a visit to A.E.R.E., Harwell. Mr. P. J. C. Perry is the conference secretary.

April 28 to May 2.—Royal Society of Health Congress, Eastbourne. Papers include "Architectural Problems Relating to the Use of Ionizing Radiations" by G. W. Mullett, M.A., physicist, Birmingham Regional Hospital Board, and "The Safe Disposal of Waste from Atomic Energy Establishments" by B. A. J. Lister, M.Sc., Ph.D., A.R.C.S., D.I.C., F.R.I.C., group leader (operations), health physics division, A.E.R.E., Harwell. Address of the Society is 90 Buckingham Palace Road, London, S.W.1.

1960

April 6 to 9, 1960.—International Congress on Mineral Processing, London. Papers should cover fundamental and applied research and development in the fields of mineral dressing, chemical processing, roasting, cyanidation, leaching, and solvent extraction. Inquiries should be addressed to the Secretary, Institution of Mining and Metallurgy, 44 Portland Place, London, W.1.

Patents Reviewed

These abstracts have been made from British Patent Specifications, complete copies of which can be obtained from the Patent Office, 25 Southampton Street, London, W.C.2, at 3s. 6d. each (including postage).

B.P. 781,100. Production of beryllium. L. J. Derham. To: National Smelting Co. Ltd.

Beryllium fluoride and magnesium in admixture are compacted and charged into a body of molten calcium chloride. The mass is then heated in a sealed vessel to a temperature above the melting point of beryllium.

B.P. 781,317. Apparatus for use in welding concentric pipe assemblies. C. T. L. O'Grady. To: U.K. Atomic Energy Authority.

After welding the inner pipe, which is arranged to stick out over the outer pipe by 4 in., so that the weld is easily made; units of sector-shaped pads with flexible edges are inserted in the space between inner and outer pipes, each unit forming, with the walls, a sector of an annular cavity. Gas (argon) is fed into the cavity through an arcuate perforated tube to set up a gas purge, to be discharged through another tube while the outer weld is being made.

B.P. 781,594. Process for coating metals. R. L. Samuel. To: Diffusion Alloys Ltd.

The metal is first coated with a liquid or pasty composition containing chromium or chromium alloy in powder form, together with a carrier which is solid at room temperature but liquid at the operating temperature (a halide other than chromium halide). The coated metal is then heated by a high-frequency current. A bonding agent (organic silicate) may be present.

B.P. 781,648. Nuclear reactor. R. V. Moore, K. H. Dent, J. H. Bowen. To: U.K. Atomic Energy Authority.

A natural uranium fuelled reactor for the economic generation of electricity. The moderator structure inside the pressure vessel is formed with vertical fuel elements in channels symmetrically arranged on a regular lattice in groups. Control-rod channels are also arranged on a regular lattice each centred on one of the groups. A coolant circuit is connected with the pressure vessel above and below the moderator structure. Through the shielding around the pressure vessel and through the vessel extend control-rod channels with a control-rod driving mechanism surmounting shielding plugs in access holes vertically above the channels. For fuel charging, chutes are introduced into the access holes. The vertical orientation has a number of advantages regarding support of the structure, arrangement of control rods (falling by gravity on failure of the mechanism), operating space, shielding.

B.P. 781,726. Process for removal of cations from aqueous solution. E. Gleuckauf, P. J. O. Roberts. To: U.K. Atomic Energy Authority.

The aqueous solution containing cations is brought into contact with a solid anion exchange substance, insoluble in water and having, at the exchange positions, anions which will form insoluble compounds with the cations. All metal ions except those of alkali metals, may be precipitated. These cations may also be separated from each other, or from those of the alkali metals. The precipitate formed on the anion exchange substance may be removed by washing with a suitable aqueous acid or complexing agent. Anion's mentioned are hydroxide, carbonate, sulphide or chromate.

B.P. 781,721. Extraction of uranium compounds. T. V. Arden, F. H. Burstall, K. P. Linstead.

Extraction with an organic solvent containing a cyclic ether. Solvents containing the furane nucleus, especially hydro-carbon-substituted tetrahydrofurane, have been found to give high extractions of uranyl nitrate from aqueous solutions.

B.P. 781,775. Go-devils. S. Jefferson. To: U.K. Atomic Energy Authority.

In order to find the position of go-devils jammed in a pipeline, a source of radio-activity may be incorporated or attached, so that the go-devil may be found by a detector of radio-activity even under several feet of earth. However, an unshielded source may be dangerous where remote handling for freeing the go-devil is not possible. The pressure-sensitive arrangement of a screening pot, e.g., a lead cylinder with a small axial bore, on the holder for the radio-active source which is withdrawn from the source at the operating pressure in the pipeline but goes into screening position at atmospheric pressure, will protect persons when freeing the go-devil, e.g., by cutting the pipeline.

B.P. 781,790. Production of N-substituted o-diamines. E. S. Lane, C. Williams. To: U.K. Atomic Energy Authority.

An N-aryl-o-diamine is prepared by a method in which an aryl-lithium compound is reacted with a benzo 2:1:3 thiadiazole or selenium or oxygen analogue thereof.

B.P. 782,148. Heat treatment of titanium alloys. To: Armour Research Foundation of Illinois Institute of Technology (U.S.A.).

A stable titanium base alloy for use at high temperatures containing 2 to 8% aluminium, 1 to 6% molybdenum (aluminium at least twice molybdenum content) which has been held at 1,500 to 1,650°F for 4 to 24 hours to coarsen the microstructure to form a continuous alpha phase. This is quickly cooled, then aged at 1,000 to 1,200°F for 4 to 48 hours, until the beta phase becomes "dark etching." The treatment counteracts the tendency towards embrittlement.

B.P. 782,752. Inspection method and apparatus. , M. Middleton, W. F. Stevenson, D. B. Smith. To: Rolls-Royce Ltd., U.K. Atomic Energy Authority.

Refers to the detection of cracks or flaws in flexible hoses, e.g., made by bonding rubber on canvas (for hydraulic and fuel systems). The hose is first subjected under pressure to a liquid including a radio-active isotope in solution. The liquid is then removed and the hose examined by a device for sensing radio-activity (Geiger-Müller tubes). Where radio-active liquid is occluded a normal radio-activity will be sensed. The radio-active isotope recommended is cerium 144-praseodymium 144.

B.P. 782,888. Nuclear reactors. To: Deutsche Gold- und Silber-Schneideanstalt, vorm. Roessler (Germany).

Beryllium metal or beryllium alloys are used as moderator in the shape of blocks traversed by cooling ducts. The cooling ducts are thus independent of the fuel arrangement. The fuel need not be canned, but can be in metallic thermal contact with the moderator, as it has been found that there is no danger of any penetration of the radio-activity of the fission products into the coolant. Metallic contact between fuel and moderator (uranium and beryllium) can be produced by mechanical compression, shrinkage, or by a liquefied substance cast into suitable cavities (sodium potassium, lead, bismuth). The blocks (of 10 to 100 kg) may form the structural elements for building up the reactor. The fuel substance may be balls or cylinders of small specific surface.

B.P. 782,922. Moderator and reflector structures for nuclear reactors. E. Long, F. G. Greenhalgh. To: U.K. Atomic Energy Authority.

A series of elastic bands built up of joined links is arranged around the structure. Each link consists of a nest of coaxical tubes, every second tube being provided with an exterior flange at one end and an interior flange at the other end, between which is mounted a flangeless tube. The tubes are then alternately under equal tension (flanged) and equal compression (flangeless), and the tension in the bands is transmitted as a centripetal load to the walls of the moderator and reflector structure.

B.P. 782,943. Removal of heat exchange medium from heat exchange systems. A Bell. To: Foster Wheeler Ltd.

Refers to the removal of residual metal from systems in which, e.g., sodium or a sodium/potassium alloy is circulated as heat exchange medium. When the bulk of the metal has been drained off (after a shut-down of the system) small amounts of metal will be left in pockets and crevices. The system is freed from these last traces by passing dry superheated steam under low pressure through the circuit while maintaining the temperature above the melting point of the metal and above the condensation temperature of the steam. The steam reacts with the metal to form hydrogen (vented out) and metallic oxide to be dissolved in and washed out by water.

B.P. 782,982. Preparation of the hexa-fluorides of uranium and plutonium. C. J. Mandleberg, R. Hurst, H. K. Rae. To: U.K. Atomic Energy Authority.

Elemental fluorine is reacted with an oxide of uranium or with an oxide or the tri-fluoride of plutonium at a temperature in the range of 550 to 650°C.

B.P. 782,997. Ceramic substances derived from chromium sesquioxide.

An intimate mixture of finely divided chromium sesquioxide and metal powder is heated to a temperature of 1500 to 1800°C. in an inert atmosphere. The metal powder is employed in amount to give a product wherein the ratio Cr : O is 1 to 1.2—1.4. The product sinters at elevated temperatures and may be compacted (cold or hot pressing, sintering) with or without a cementing metal or by bonding with organic resin. The material is of great hardness (for cutting tools or high temperature use under oxidizing conditions).